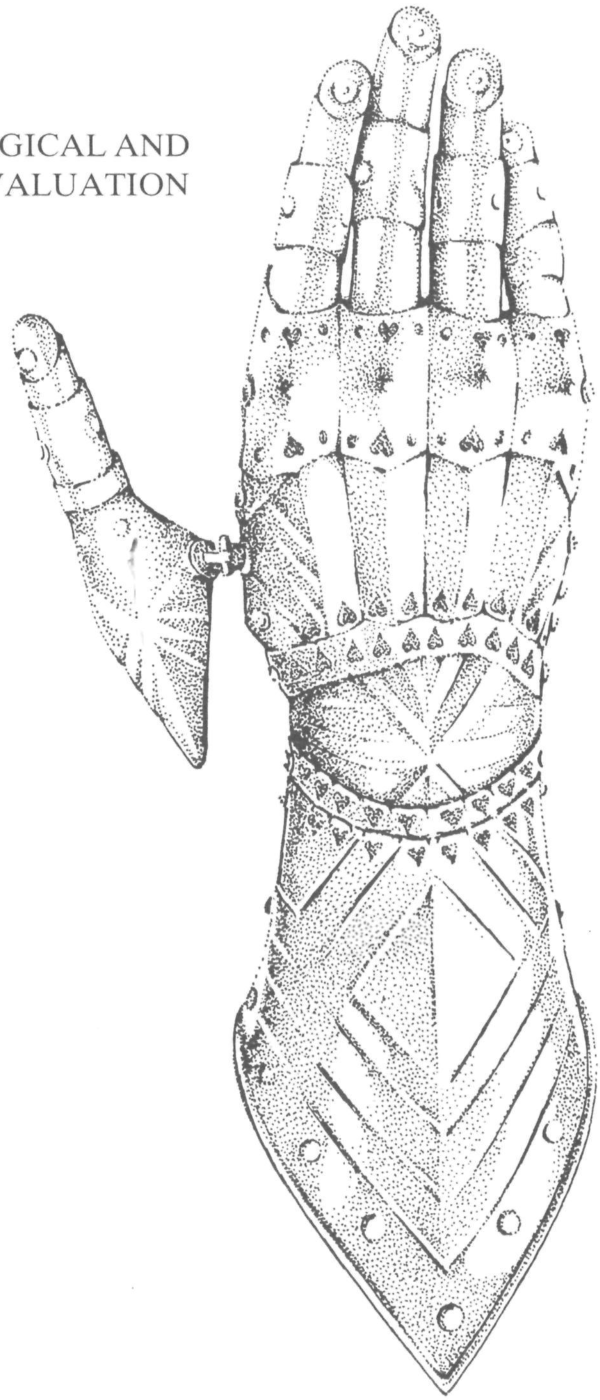
THE ARTHRODESIS OF THE WRIST JOINT



A CLINICAL, ROENTGENOLOGICAL AND ERGONOMIC EVALUATION OF 66 CASES

J.G.W.A. VAN GEMERT

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PROEFSCHRIFT

TER VERKRIJGING VAN DE GRAAD VAN DOCTOR IN DE GENEESKUNDE
AAN DE KATHOLIEKE UNIVERSITEIT TE NIJMEGEN,
OP GEZAG VAN DE RECTOR MAGNIFICUS
PROF. DR. J.H.G.I. GIESBERS
VOLGENS BESLUIT VAN HET COLLEGE VAN DEKANEN
IN HET OPENBAAR TE VERDEDIGEN OP
DONDERDAG 15 MAART 1984 DES NAMIDDAGS OM 2.00 UUR PRECIES

DOOR

JOHANNES GERARDUS WILHELMUS ANTONIUS VAN GEMERT

GEBOREN TE DIEMEN

1984

Druk: Grafisch Service Centrum Nijmegen b.v.

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PROMOTORES: PROF. DR. T.J.J.H. SLOOF
PROF. DR. J.M.G. KAUER

Translated by C. Visser and M. Henkes, Eindhoven.

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voor wie mij lief is....

Matteüs 25, 14-30

Dit proefschrift kwam tot stand onder leiding van Prof. dr. T.J.J.H. Slooff en Prof. dr. J.M.G. Kauer, resp. Hoogleraar in de Orthopaedie en Hoogleraar in de Anatomie en Embryologie aan de R.K. Universiteit van Nijmegen. De patientengegevens gebruikt voor dit na-onderzoek zijn afkomstig uit de Orthopaedische afdeling van het St. Radboudziekenhuis en van de St. Maartenskliniek te Nijmegen en werden welwillend ter beschikking gesteld door Prof. dr. Th.J.G. v. Rens en Drs. G.Th.M. Bossers.
De basis voor deze studie kon in 1975 en 1976 nog in Nijmegen worden gelegd, waarna ondanks vertragingen, de voltooiing vanuit Alkmaar zijn beslag kreeg.
Hierbij dient zeker de steun van mijn associe's Drs. P.C.G. Hubach en Drs. F.J. Custers vermeld te worden, evenals de kritisch stimulerende begeleiding door Dr. C.M.T.J.M. Plasmans.
Het ergonomisch onderzoek had nooit uitgevoerd kunnen worden zonder de hulp van mej. P. Vleugel.
De röntgenologische evaluatie vond plaats onder leiding van Drs. W.M. Oudesluys waarbij mej. B. v.d. Laar ons administratief terzijde stond.
Computerregistratie en statistische bewerkingen werden gedaan door dhr. W. Lemmens van het M.S.A. (Hoofd Drs. P. v. Elteren). Zijn kritische begeleiding heeft sterk kwaliteitsverbeterend gewerkt.
Dhr. Ed Noyons tekende voor de illustraties, terwijl de heer T. van Hout de fotoregistratie verzorgde.
Mevr. T. Olij en mevr. R. Fliervoet is grote dank verschuldigd voor het vele – herhaalde – typewerk t.b.v. dit manuscript.
Een woord van dank past ook aan al de niet-genoemden, die door ideeën, bemoediging en troost een steun bij alles zijn geweest.
Echter speciaal en met grote genegenheid wil ik hier vermelden de zusters Carmelitessen uit Egmond aan den Hoef, die vanuit hun unieke traditie mij in bepaalde perioden onontbeerlijke geestelijke en morele steun en inspiratie wisten te geven.
Apart wil ik nog noemen mijn moeder, die op haar eigen wijze tot het stand komen van dit proefschrift heeft bijgedragen.
Ik hoop, dat de voldoening van deze dag – de 75e geboortedag van mijn vader – haar tot vreugde mag zijn.
Het is om haar en hem te eren, dat de keuze op deze dag is gevallen.
Het laatste woord is echter gewijd aan mijn vrouw, die ondanks de drukte en problemen van de orthopaedische praktijk, zich niet alleen wegcijferde ten behoeve van dit proefschrift, maar die ook op wezenlijke momenten een grote beslissende stimulans wist te zijn.
Zonder haar was dit proefschrift nooit tot stand gekomen.
Het dient tenslotte ook beschouwd te worden als onze "tweemans klus".

'Our hands become extensions of the intellect, because by hand movements the dumb converse, with specialized fingertips the blind read, and through the written word we learn from the past and transmit to the future'.
Sterling Bunnell 1964.

PART I

CHAPTER I. INTRODUCTION

Now that articular endoprostheses have started their indefatigable advance, providing orthopaedic surgery with ever more possibilities of reconstruction, the time has come for reappraisal of the indications for arthrodetic procedures.

Arthrodesis, namely, sacrifices any residual function to abatement of pain and stability. The heavier the demands on a joint, especially where weight-bearing is concerned, the sooner the indication for arthrodesis will continue to exist for that joint. In this respect, namely, the endoprosthesis is inferior to arthrodesis. One of the joints to which this applies in particular is the wrist joint (Swanson, 1973, 1977; Volz, 1976, 1977; Meuli, 1972, 1973, 1974, 1977 and 1980; Beckenbaugh; 1976, 1977 and 1980).

The wrist joint is the base of the hand which is why pathology of this joint readily leads to impairment of the function of the hand. This correlation is aptly reflected in the German term 'Handgelenk' (hand joint) and the (rarely used) Dutch term 'handwortel' (root of the hand). The wrist joint provides the hand with a unique combination of possible movements: dorsopalmar flexion and radioulnar abduction; rotation of the hand in the wrist joint is not possible.

Anatomical and clinical research has long made it clear that these movements are the result of a complicated mechanism (Navarro, 1937; Landsmeer, 1961; Scaramuzza, 1969; Linscheid et al, 1972; Kauer, 1980). In this mechanism, an important part is played by the interdependence of changes of position of carpal bones in relation to each other. Mechanically, the wrist joint may be regarded as a system that provides two degrees of freedom of movement, and functioning as such in the articular chain of the upper limb as a whole makes an essential contribution to the possibilities of the hand to position itself freely in space. Therefore, arthrodesis of the wrist joint – the joint between the forearm and the hand – will affect not only the ways in which the hand can move, but will impair the function of the upper extremity as a whole.

This study was aimed at evaluation of the results of arthrodesis of the wrist joint in regard to their clinical and radiological as well as their ergonomic aspects. This evaluation has been part of a follow-up examination of 65 patients with 66 wrist arthrodeses. Most of these operations have been performed according to one of two different techniques, between 1961 and 1974, either in the St Maarten Clinic (Head Dr G. Bär, later Drs G.Th.M. Bossers), Nijmegen or in the orthopaedic clinic of the St Radboud Hospital (Heads Prof. Dr G. San Giorgi, Prof. Dr G. Chapchal and Prof. Dr Th.J.G.

van Rens), Nijmegen.
An ergonomic evaluation method for qualitative and quantitative assessment of the function of the hand after wrist arthrodesis was developed especially for this study.

II.1. Functional anatomy of the wrist joint and the hand

The wrist is the flexible junction between the hand and the forearm. From this joint the hand derives a high degree of mobility, with a unique combination of possible movements: dorso palmar flexion and radio ulnar abduction; rotation of the hand in the wrist joint is not one of the possible movements (rotation of the hand in the form of pronation and supination takes place in the proximal and distal radio ulnar joints). The total range of movement in dorsopalmar flexion averages 150° (Von Lanz and Wachsmuth, 1959). In radioulnar abduction, the total functional range averages 60°. In this connection, it should be noted that the possible degree of flexion and the possible degree of abduction are interdependent, which implies that extreme flexion cannot be combined with extreme abduction.
The pronation-supination –150°–, on the other hand, can be utilized in its entirety independently of the position of the wrist joint (De Leeuw, 1962). Consequently, combination of possible movements of the carpus and of the radioulnar joints provides the hand a vast range of possibilities of specific positioning.

In the wrist joint we can distinguish (Fig. 1):
- the radiocarpal level
- the carpal level
- the carpometacarpal level.

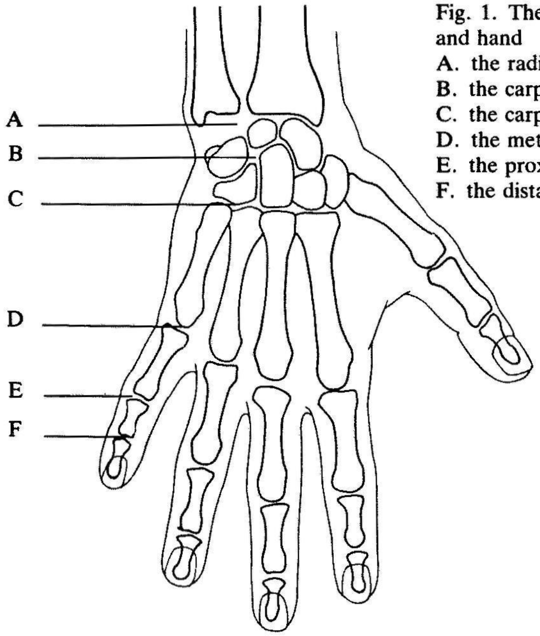


Fig. 1. The articular levels of the wrist joint and hand
A. the radiocarpal level
B. the carpal level
C. the carpometacarpal level
D. the metacarpophalangeal level
E. the proximal interphalangeal level
F. the distal interphalangeal level

II.1.1. The radiocarpal level

At the radiocarpal level, the radius and the articular disc articulate with the proximal carpal bones: scaphoid bone, lunate bone and triquetral bone (the pisiform bone should be regarded as a sesamoid) (Fig. 1, Fig. 2).
Running obliquely over the junction between the carpus and the radius and the articular disc, there are ligamentous systems that preclude rotation at the radiocarpal level (Vallois, 1926). Taleisnik (1976) in his description of the function of the ligaments of the carpal joint, distinguishes the latter, or extrinsic ligaments from the intrinsic, short, fairly strong ligaments that connect the carpal joints with each other.

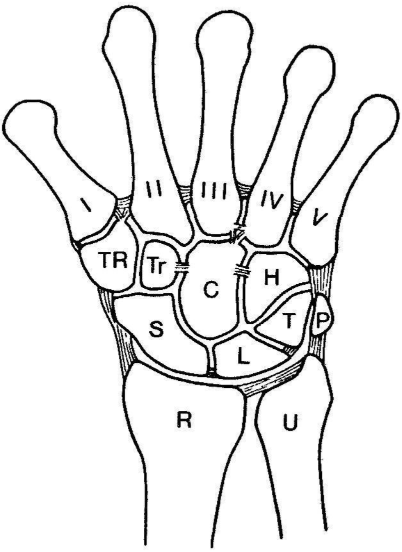


Fig. 2. The carpal bones
I = Ist metacarpal bone
II = IInd metacarpal bone
III = IIIrd metacarpal bone
IV = IVth metacarpal bone
V = Vth metacarpal bone
TR = trapezium bone
Tr = trapezoid bone
C = capitate bone
H = hamate bone
S = scaphoid bone
L = lunate bone
T = triquetral bone
P = pisiform bone
R = radius
U = ulna

II.1.2. The carpal level

At the carpal level we observe a complicated interplay of bones and ligaments. The bones are arranged into two transverse rows (Fig. 2):
– The distal row, consisting of the trapezium, trapezoid, capitate and hamate bones.
These bones, with the exception of the trapezium bone, are very firmly bound together by short, fairly strong ligaments that preclude movements of the bones in relation to each other.
– The proximal row, consisting of the scaphoid, lunate and triquetral bones, bound together in such a way that displacements of the bones in relation to each other are possible.

Extensive studies have been made of the mechanism of the wrist joint, in the second half of the last century and the first few decades of this one, especially after the introduction of radiography as a method of examination. Reference may be made in this connection to the works of Günther (1850), Henke

(1859), Bryce (1896) and Fick (1901, 1910).

During this period, a functional concept arose which for a long time has played an important part in the kinematic-analytical and biochemical research of the wrist joint. This concept is essentially based on the view that the two transverse carpal rows, proximal and distal (during flexion and abduction of the hand in relation to the forearm) change position in relation to each other and in relation to the radius and the articular disc as solid bodies. This implies that in determining the movement, each of the two articular levels, the 'mediocarpal joint' and the 'radiocarpal joint' plays its part as a unit, a part that depends on the range and the direction of the movement.

Another basic element of this concept is that movements in the wrist joint as a whole take place between evenly curved articular surfaces, rendering it possible to postulate one fixed axis of movement for the flexion and one fixed axis of movement for the abduction of the hand, with the discussion limited largely to the precise direction and localization of these axes.

Occasional use of this concept can still be observed (Von Lanz and Wachsmuth, 1959). In addition we may establish that the concept is insufficiently well-founded to serve as a model in the evaluation of the clinical aspects of the wrist joint. In this respect it should be noted that any impairment of the normal function originates in the longitudinal rather than in the transverse articular structures(Gilford, 1943; Mayfield, 1980; Taleisnik, 1980).

Gilford (1943) was the first to regard the joint as a system of three interlinked parallel longitudinal chains, in each of which chains a proximal carpal bone (the scaphoid, lunate and triquetral bones, respectively) functions as an intercalated bone. Landsmeer (1961) was the first to present a detailed discussion of the functional position of the intercalated bones, and of the ways in which they may change position.

One important observation is that the proximal and distal articulations which the intercalate bone forms should move in harmony to ensure balance in the chain. The interdependence of the three longitudinal chains plays a part in this connection (Kauer, 1974). This concept implies that failure of this single carpal bone to function normally will necessarily lead to impairment of the entire carpal mechanism. This means that partial stiffening of the wrist joint will severely disturb the function of the articulation.

The concept of longitudinal chains was introduced as early as 1919 by Navarro (1937), and it was adopted in 1969 by Scaramuzza and in 1978 by Taleisnik, none of whom, however, specified the conditions to which such a system has to be subject.

Further, Linscheid et al (1972) have attempted to arrive at an explanation of carpal instabilities with the aid of mechanical models based on a construction principle in which longitudinal chains play a part. However, these concepts provide no answer to the question just what it is that effectuates the conjunction of changes of position at the mediocarpal and radiocarpal levels during motions in the wrist joint.

Functional morphological studies of the wrist joint have supplied relevant data in regard to the importance of the shape of the intercalated bones, the shape of the articular contacts and of attachments between the bones ((Van Lamoen in Matricali (1961); Kauer (1964, 1974, 1980); Mulder (1970); Kauer and Landsmeer (1981)).
As a result, more insight has been gained into the ways in which changes of position of the intercalated proximal carpal bones are brought about, and into the part played in this connection by the interlinking of the three longitudinal chains in the carpal joint. This concept appears to constitute a good foundation for kinematical analysis (Berger, 1980, 1982; De Lange, 1983), which may provide quantitative data in regard to the possibilities of motion of the carpal bones. Such data are indispensable in testing the validity of the concept and in the clinical evaluation of the conditions to which such a system has to be subject.

II.1.3. The carpometacarpal level

The junction between the carpus and the metacarpus is made up by the carpometacarpal (C.M.C.) joints (Fig. 1). For functional reasons, a distinction is made between the C.M.C. joint of the thumb and the C.M.C. joints of the other digits.
The construction of the C.M.C. I joint and its ligamentous system render it more flexible than the other C.M.C. joints, so that it occupies a position of its own. The mobility of the C.M.C. joints II-V is limited by the shape of the articular surfaces and by the type of ligamentous interconnection. Mobility is particularly restricted in the second and third C.M.C. joints; in the ulnar direction, the mobility in the C.M.C. joints increases gradually (Benninghoff, 1961).
A study by Dubousset (1981) reveals the following flexion-extension mobilities in the C.M.C. joints:
in C.M.C. II : a few degrees;
in C.M.C. III: also a few degrees, or even less;
in C.M.C. IV: approx 10°;
in C.M.C. V : approx 25°.
The basal articular surfaces of the metacarpal bones, especially of M.C. IV and V, allow a cylindrical-conical motion in which abduction/adduction movement and flexion/extension movement are combined. Thus, a broadening of the palm of the hand is brought about by extension and spreading of the metacarpal bones – the metacarpal arch flattens – and a narrowing and cupping of the palm during flexion in the C.M.C. joints – the metacarpal arch is enhanced (as e.g. in making a fist) (Fig. 3).
In addition, there occurs a rotation of the mobile metacarpals, a pronation-directed rotation during extension and a supinatory rotation during flexion. The importance of this possibility of rotation lies in the fact that not only does it contribute to the mobility of the fingers but in addition it renders it possible

Fig. 3. The metacarpal arch

for the palmar parts of the fingers to be brought into contact with objects of various shapes.

The C.M.C. joint of the thumb, on the other hand, allows a broad range of motion. It is a saddle joint and the ample possibilities of motion are explained by the structure and localization of its ligaments (Pieron, 1973). The mobility of this first metacarpal is increased further by the mobility of the trapezium bone in relation to the other distal carpal bones. According to Benninghoff (1961), from the functional point of view this is a ball-and-socket joint, and this is confirmed by Pieron's investigation:

If the right hand grasps the terminal phalanx of the left-hand thumb, the thumb may be rotated as if round a cone with an oval base and in addition be rotated around its longitudinal axis.

These movements may be reduced to two basic movements round axes both situated in the saddle joint. One other movement consists of abduction/adduction round a dorsovolar axis. The other consists in opposition/reposition of the thumb round an axis that makes an angle of 90° with the abduction-adduction axis. During these changes of position, some degree of rotation of the first ray occurs as a combined movement. This rotation is imposed by the system of ligaments around the C.M.C. I joint (Pieron, 1973). Axial rotation of M.C. I by itself is not possible because the shape of a saddle joint precludes this (Kuczynski, 1974).

It may be emphasized that it is precisely the possibility of opposition and the resulting rotation of the first ray that make the palmar surface of the thumb face the palmar surfaces of the hand and fingers. The functional importance of this will emerge from the discussion of the manual grips.

II.1.4. The metacarpophalangeal and the interphalangeal levels

The fingers articulate with the metacarpal bones by means of the metacarpophalangeal (M.C.P.) joints (Fig. 1). These are condylar joints the collateral ligaments of which tense during flexion. This precludes the lateral mobility that exists in extension. An extended finger can perform a circumduction. An exception to this rule is the M.C.P. joint of the thumb which permits neither rotation nor circumduction. In the 'first ray' most of the mobility is permitted by the carpometacarpal joint; the metacarpophalangeal joint exclusively allows a flexion/extension movement (Von Lanz and Wachsmuth, 1959; Benninghoff, 1961). According to these authors, the lateral mobility in the metacarpophalangeal joints has approximately the following values:

M.C.P. II 45° ulnar abduction and 15° radial abduction
M.C.P. III 20° ulnar abduction and 20° radial abduction
M.C.P. IV 20-25° ulnar abduction and 20-25° radial abduction
M.C.P. V 30° ulnar abduction and 20° radial abduction.

In this connection Dubousset (1981) points out that the radial abduction takes place in the second metacarpophalangeal joint in combination with a pronatory movement (of 15°) and that the ulnar abduction takes place in combination with a supinatory motion. He also mentions that during flexion in the fifth metacarpophalangeal joint there occurs a simultaneous flexion in the fifth carpometacarpal joint as the result of which during the flexion movement the range of the fifth finger is relatively larger than that of the other fingers.

Dubousset (1981) also critically reviews the generally held opinion that the proximal interphalangeal (P.I.P.) joints are pure hinge joints. He concludes from his anatomical studies that owing to the shape and the asymmetry of these interphalangeal joints flexion is associated with a lateral abduction and an axial rotation movement:

- in the forefinger, flexion is associated with 0 to 5° ulnar abduction;
- in the middle finger, flexion is combined with 5° radial abduction;
- in the ring finger, this radial abduction amounts to 5 to 10°;
- in the little finger, the radial abduction as a rule exceeds 10°.

This would make the mobility in the P.I.P joint conical rather than purely sagittal.

In addition, in these P.I.P. joints (apart from the middle finger), axial rotation takes place during flexion (e.g. the central phalanx of the forefinger rotates 15° in supination during flexion; the rotations of the central phalanges of the other fingers vary. The effect of this rotation is that a maximal pulpal surface of the forefinger faces the thumb during the precision grip (see below).

In the distal interphalangeal joints (D.I.P. joints), the mobility probably is indeed a pure flexion-extension, but these joints also permit hyperextension in order to maximize the contact between the fingertips and an object to be grasped.

The combination of flexion, rotation and abduction in the C.M.C., M.C.P. and I.P. joints,respectively, has the effect that when the fingers flex in succession,starting with the forefinger, they all move toward the same point on the ball of the thumb, viz. the tuberosity of the scaphoid bone (Fig. 4).

II.2. The function of the hand

The hand may be regarded as the 'effector organ' of the upper limb

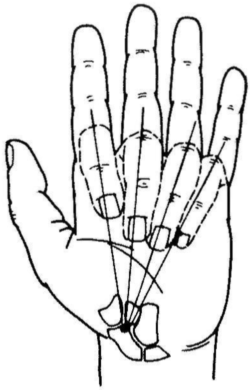


Fig. 4. During flexion the fingers point concentrically to the scaphoid bone

(Kapandji, 1980). The facilities of motion in the upper limb render it possible for the hand to position itself optimally in space, in other words to assume the optimal position for the performance of a particular act. However, the hand is not just a motor organ, it is also a highly sensitive recording instrument. It is an organ of touch and prehension. Thomas (1952) defines prehension as a cortically controlled action aimed at grasping an object that has been seen or touched, as later emphasized once more by Malek (1981). The definition emphasizes the important role of the brain and the tactile organs in the function of the hand (Fig. 5).

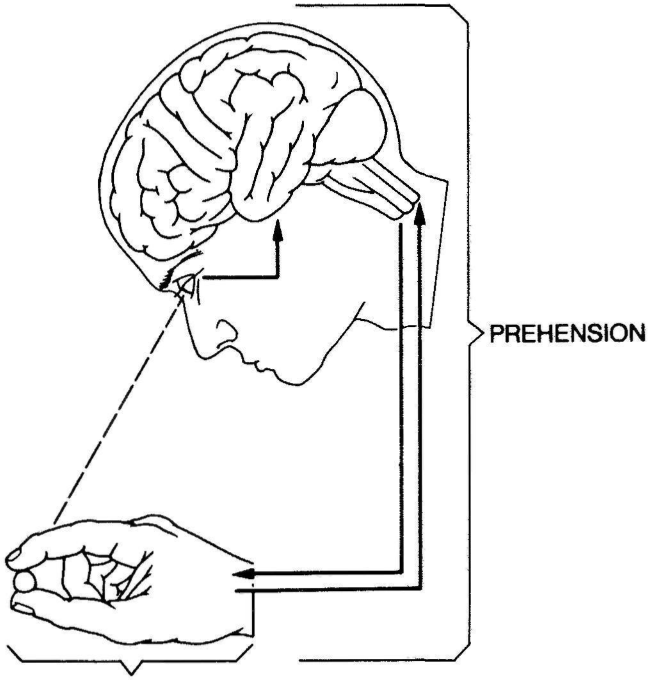


Fig. 5. Prehension and grip

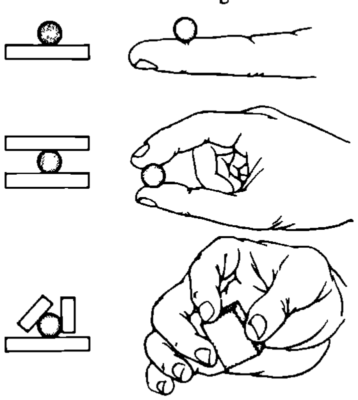
The principal motor activity of the hand is the grasping, the temporary union of hand and object, the result of muscular action on the joints described above. The word 'Grip' rather than 'Prehension' should be used to describe the actual moment of the action:
the moment of the hand seizing the object, while prehension should be distinguished from grip because it includes all the functions applied to seize an object, before, during and after the actual grasping. In the grasping function we may distinguish such elements as motion, force, speed, endurance and stabilization, stabilization being defined as the capacity to maintain the relative position achieved by the motion.
The grasping depends on two categories of factors. On the one hand, the physical aspects of the object to be grasped: size, shape, surface, temperature and weight and on the other, the fact that the grasping changes under the influence of the position to be assumed by the hand. During prehension, we see that as soon as the hand starts to move toward the object, it begins to adapt the grasping position desired, but this position is constantly adjusted to allow grasping of the object with optimal efficiency.
The forces that play a part in grasping can be subdivided as follows:

a. Forces required to hold, displace or use the object (especially gravity, kinetic force);
b. Forces of the hand itself: forces of the intrinsic and extrinsic muscles, manifesting themselves in the fingers and the fingertips;
c. friction forces, if the object can move in relation to the skin.

The contacts between the object and the hand can be subdivided as follows:

- Unilateral: e.g. the palm of the hand supports an object (force on one side);
- Bilateral: the object is wedged in from two sides (the forces come from two sides);
- Multilateral: the object is gripped from several sides. In this case, an object may be held motionless in the hand (Fig 6).

Fig. 6. The contact of the object with the hand



A. unilateral contact

B. bilateral contact

C. multilateral contact

Accordingly, in most grips there are more than three points of contact between the hand and the object, through which several variable forces may be transmitted to the object.

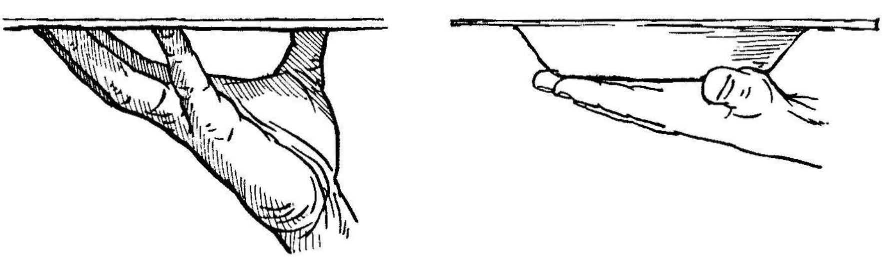
II.2.1. Mechanical classification of the manual grips

In the literature, the manual grips are subdivided into the following chief types (McBride, 1942; Slocum and Pratt, 1946; Taylor and Schwartz, 1970; Kunte and Platzer, 1980; Malek, 1980):

A. *The platform grip*
   This is a unilateral grip with the hand, in fact, counterbalancing the object (Fig 7).
B. *The pinch*
   In which type of grip two (or more) osseous columns together form a clamp. This type of grip may be bilateral but more often is multilateral with the following subdivision:

1. the thumb-finger pinch (thumb opposed to the fingers) (Fig. 8)
2. The whole hand grip (with the fingers, thumb and palm forming a clamp) (Fig. 9)
3. The digito-palmar pinch (with the fingers flexed on the ulnar side in relation to the surface of the palm and the base of the hand) (Fig. 10).
4. The interdigital pinch (a squeezing between the sides of the fingers) (Fig. 11).

Fig. 7. The platform grip. (The object rests on the palmar surface of the hand and/or fingers)



A. partial palmar contact (pulp contact) B. complete palmar contact (whole hand contact)

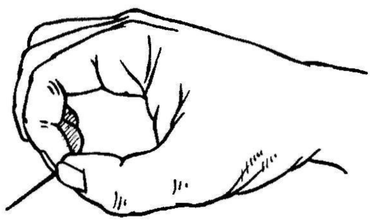
Sub A. *The platform grip*

For this grip, the hand is held flat. The object rests on part or on the whole of the palmar surface of hand and/or fingers; thumb and fingers may be spread. In this manner, the object cannot really be held firm, however (Fig. 7).

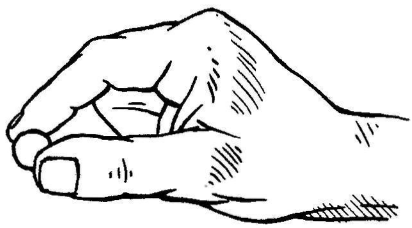
Sub B. *The pinch*
In the bilateral pinch, at least one of the compressing elements is a finger. If more force is required, more gripping surfaces are applied and the grip becomes multilateral.

1. *The thumb-finger pinch*: Here, the thumb opposes the forefinger. This grip is not very firm but allows a very sensitive touch. We may further distinguish the *finger/nail pinch*, which specifically uses the nails of thumb and/or forefinger (e.g. to pick up pins etc from a smooth surface) (Fig. 8A).
A more widely used grip is the *pulp grip* (fingertip grip) for which the pulpal surfaces of the thumb and one or more fingertips are pressed together (e.g. to hold a playing card, a coin, etc). This pulp grip may be performed with the thumb and one finger in which case it is bilateral, (Fig. 8B) or it may involve the tips of two or more fingers, in which case this 'pulp grip' is multilateral (Fig. 8C).
A third variant of the thumb-fingerpinch is the *key grip*: The object is held between the pulpal surface of the terminal phalanx of the thumb and the radial surface of the distal forefinger (Fig. 8D).

Fig. 8. Thumb-finger pinch

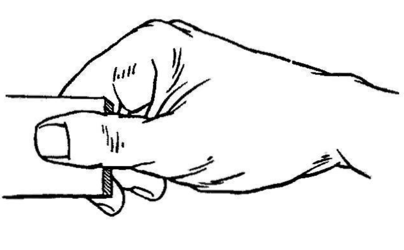


A. the finger-nail grip: the object is held between fingertip and nail



B. the pulp grip: bilateral: the object is held between 2 fingertips

C. the pulp grip: multilateral: the object is held between several fingertips

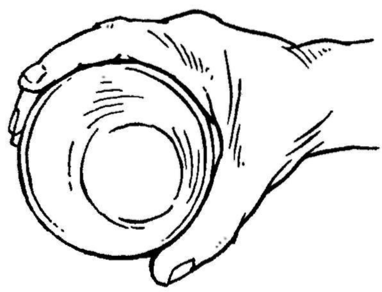


D. the key grip: between the pulpal surface of the thumb and the radial surface of the index

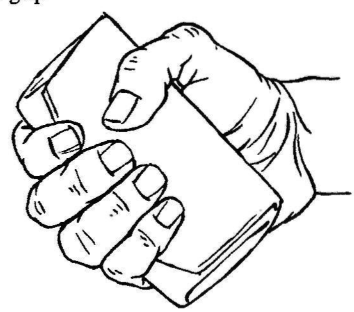
2. *The whole hand grip* (comprehensive grip). Flexion of, especially, the radial fingers brings their palmar surfaces opposite to the thumb and the eminences of the thenar and hypothenar. The palm grows more or less

cupshaped and a cylindrical or spherical object may be enclosed by the fingers (*Cylinder grip,* (Fig. 9A), *ball grip* (Fig. 9B)). These grips, in which the fingers face the opposed thumb and palm can only be performed completely if the hand can be stabilized in slight dorsiflexion (by means of the carpal extensor muscles innervated by the radial nerve). The cylinder grip is then completed by flexing the fingers. This grip is highly suitable to keep a firm grasp on all kinds of objects.
In these situations, in which a firm hold has to be combined with good possibilities of manipulating the object held away from the body, i.e. more or less in line with the forearm, use is made of the same type of grip but now with the hand in ulnar deviation in relation to the forearm; certain authors call this the *directional grip* or the *lateral grip* (Fig. 9C).
In this case, the little finger as a rule locks the object against the arch of the hand. For the cylinder grip, the fingers are pressed together, whereas for the ball grip the fingers are spread more and the palm of the hand is arched more.

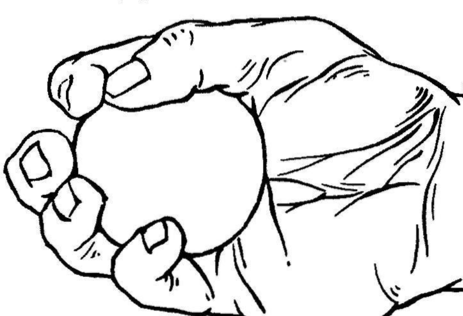
Fig. 9. Whole hand grip



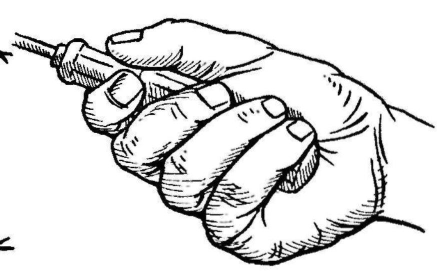
A: cylinder grip



A: cylinder grip



B: ball grip

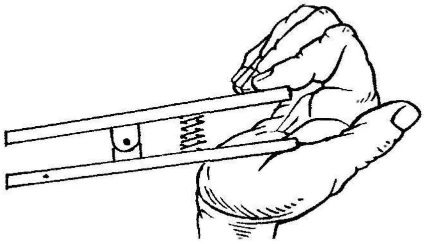


C: lateral grip (directional grip)

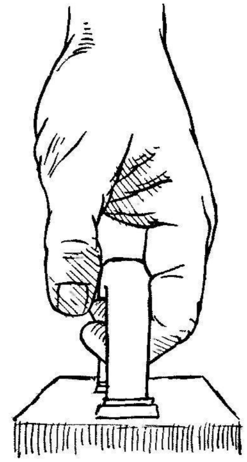
3. The *digitopalmar grip*. In theory, the thumb is not involved in this grip: the flexed fingers face the proximal part of the hand and the third point of support is the row of flexed fingers, or at a longer distance, the thumb (Fig. 10A).
The thenar eminence may also serve as a point of support. The flexed fingers, with the pulpal surfaces parallel and at some distance from the palm, form a

hook: '*hook grip*' (Fig. 10B).
Maintaining this grip requires relatively little muscular effort and it may be used under circumstances in which precision plays very little part but in which force has to be exerted continuously for a long time, e.g. carrying of shopping or travelling bags. This hook grip is also used when for some reason it is impossible to exert force with more than one finger, e.g. while opening a sash window, lifting a sewer cover by a ring, etc.

Fig. 10. Digitopalmar grip

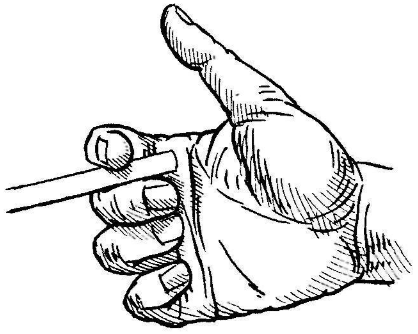


A: the object is held between flexed fingers and proximal palm



B: hook formed by flexed fingers; the function of the palm is additional

Fig. 11. Interdigital pinch



The object is pinched between the lateral surfaces of the fingers (bilateral contact)

Slocum and Pratt have quantified the above three grip types for purposes of handicap assessment. They allot 30% of total manual function to the thumb-finger pinch, 50% to the whole hand grip and 20% to the digito-palmar grip provided sensitivity is intact; for loss of sensitivity they reduce these values by 50%.

4. *The interdigital pinch*. Mechanically considered, this is not very efficient. Use is made of the sides of the digital elements and the forces are transmitted by soft parts that are thinner and shift more readily than on the flexor side. The muscular forces are relatively weak and these pinches are used only to grasp light objects or to compensate for loss of the thumb (Fig. 11).

II.2.2. *The functional approach to the manual grips*

Many authors – as Napier wrote in 1956 – base their classifications of manual functions-grips on the functional end results of the actions involved. Napier himself, followed by Landsmeer (1962), on the other hand, essentially considered and analysed the possibilities of the hand as an entity. Napier on functional-anatomical grounds arrived at two different basic types of motion: 'precision grip' and 'power grip', which singly or in combination constitute the basis for all grasping activities, for fine as well as for coarse movements. The essential element of a grip is the ability to hold an object with manual shape and force adjusted to that object. This depends on stability in the joints and on stabilization by joint-controlled structures. Without this ability, manual function loses its precision.

During the basic motion called the power grip, the object is held between the partially flexed fingers and the palm, counter-pressure being exerted by the thumb that lies more or less in the plane of the palm.

During the precision grip, the object is held between the flexor surfaces of the fingers and the opposed thumb. Even though the type of grip depends to a considerable extent on the physical shape of the object, the grip pattern clearly will also be influenced greatly by the way in which the object is to be moved. Consequently, most grasping motions include elements of the power grip as well as of the precision grip. Whether a grip will be classified as a precision grip or as a power grip depends on the dominant characteristic of the motion.

The term 'grip' may be interpreted either dynamically or statically. In the dynamic view, the main question is how the grip is brought about: the movements of the hand that lead to the formation of the grip.

From the static point of view, the main thing is the maintenance of the grip. The dynamic interpretation concerns the movement by which the hand adopts the desired position. In the static phase, the hand and/or fingers are adjusted to the object and become part of a lever controlled from proximal joints.

Landsmeer (1962) discusses the relevant terminology and interpretation in great detail.He prefers the terms of power *grip* and precision *handling*, and states that the power grip has greater force because more stability and motionlessness of the object are required; the hand is virtually immobile, i.e. it is in a static phase and movement takes place predominantly in the fore-arm, elbow and shoulder, whereas in the precision grip it is the motion (manipulation of the object) that is predominant; the character is clearly dynamic, hence the term of precision handling.

The power grip, unlike the precision handling, requires a fixed wrist joint.

It is pointed out in the literature that during a power grip the thumb is in maximal adduction, in the M.C.P. as well as in the C.M.C. joint, whereas in the precision grip both joints of the thumb are in abduction (Napier, 1956; Flatt, 1961; Landmeer, 1962 and Backhouse, 1968).

Capener (1956) and Hazelton (1975) conclude that the power grip may be regarded as a total manual function in which the little finger, the ring and the middle finger provide the grasping force, while the thumb jointly with the forefinger supplies the necessary precision. Precision handling is a specific function of thumb and forefinger, aided if necessary by the middle finger, while the ring finger and little finger may be used for support and adjustment of position.

Interestingly, the innervation pattern approximately reflects this distinction of functions, as follows:

the ulnar nerve supplies the power grip function and the medial nerve the precision grip functions.

The position of the hand in relation to the forearm is also clearly different in these two versions of the grip:

for the power grip, the hand is deviated in the ulnar direction and the wrist held in such a position that the longitudinal axis of the thumb is the continuation of the forearm; for the precision grip, the hand is held in the mid-position between radial and ulnar abduction with the wrist in slight dorsiflexion. This implies that fixation of the hand in relation to the forearm – as results from arthrodesis of the wrist joint – affects the precision grip and power grip to various degrees, which clearly has ergonomic consequences as well.*

In accordance with the above functional analytical distinction between power grip and precision handling, the whole hand grip may be regarded as a power grip, whereas the thumb-finger pinch is predominantly a form of precision handling.

II.3. The functional position of the hand in relation to the forearm

A topic regularly discussed in the literature is that particular fixed position of the wrist that will cause minimal impairment of manual function, in other words, is optimally acceptable from the functional and cosmetic points of view. Naturally, more value is placed on the function than on the external appearance. Accordingly, many authors (physicians as well physiotherapists, occupational therapists and ergonomists) have presented a description of this 'optimum position of function', a term ascribed to Kanavel (1933) whereas Fisk (1981) prefers to speak of 'static position' or 'position of fixation', but most of them fail to provide an adequate explanation of its importance for the function of the hand.

Apparently, many authors of orthopaedic textbooks have uncritically adopted this term without precisely analysing its meaning.

Von Recklinghausen (cited by Steindler, 1930) defined the normal or resting position of the hand as that position of the wrist in which the sum of the moments of all seven wrist muscles in all rotation planes equals 0, or in other

* For a definition of ergonomics see page 62

words, in which the combined moment of torsion equals 0. He gives this position as 12° dorsiflexion and 3° radial abduction (probably measured over M.C. II, because Steindler equates this position with that in which the longitudinal axis of M.C. III is a continuation of that of the forearm).

II.3.1. The degree of dorsiflexion

It was written as early as the beginning of this century that when a wrist had to be fixed, it had to be placed in slight dorsiflexion to provide a good gripping position and grip strength.

Robert Jones (1921) considered some dorsiflexion to be a surgical axiom, 'an axiom that does not admit of question' and recommended that all wrist injuries should be treated in this position. He considered the position to be preferable from the aesthetic point of view, as well: 'a palmar flexed wrist is always an eyesore'.

Steindler, citing Robert Jones as early as 1918, corroborates this view by stating that then the tone of the digital flexor muscles allows maximal utilization of muscle force per unit. With the wrist in complete palmar flexion and the fingers extended, on the other hand, three-quarters of the potential contractile force of flexors is found to have disappeared.

Liebolt (1938) considers a dorsiflexion between 25° and 30° ideal and corroborates this by referring to the positions in making a fist: when fingers are flexed into the palm, the wrist automatically assumes some degree of dorsiflexion to provide a optimal force, function and cosmetic appearance' In marked dorsopalmar flexion the grip is inadequate, and a hand with the metacarpal bones lying in one plane with the forearm is not in the best position for the necessary grips, either.

However, Liebolt adds an extra dimension to the 'position of function' by evaluating not only the degree of flexion in the wrist but also the degree of radial-ulnar abduction. He advances certain inconclusive arguments to assert that the wrist in this plane should be in a neutral position, i.e. in the dorsal view the axis through the shaft of M.C.should be in line with the axis of the forearm.

Most authors express a preference for some dorsiflexion in the wrist joint, ranging from 10 to 30° usually approx. 20°, see table 1).

This is argued in terms that mostly amount to the same thing: 'the position the hand adopts during rest, because in that position the muscle tones of the flexors and extensors are in balance'; slight dorsiflexion because in that position the grip force is maximal'; 'the position adopted by the wrist in making a strong fist'; 'a position in which it is easy to throw darts' (Bunnell, 1956; Campbell, 1964; Hazewinkel, 1962; Robinson and Kayfetz, 1952; Roux, 1972). Most references, however, are simply to a functional position. Rheumatological surgeons, however, adopt a much more cautious position (Clayton, 1965; Dupont and Vaino, 1968; Mannerfelt et al, 1971, 1972, 1973).

They often even regard the dorsiflexion position as contraindicated because many ADL (activities of daily life) motions have to be performed in a neutral position or even in slight palmar flexion. In these activities, namely, power is not the principal requirement, as stated above, so that dorsiflexion is less important. Consequently, the necessary grips rather fall in the category of precision handling. On the other hand, palmar flexion renders the use of a normal walking stick more difficult.

TABLE 1

Recommended positions in arthrodesis of the wrist joint

Authors	*Year*	*Degree of dorsiflexion*	*Degree of ulnarabduction*
Abbott	1942	10-15°	0-10°
Allende	1979	0°	slight
Bentley	1978	0°; 2nd wrist 15-20° palmar flexion	M.C. III in line*
Brittain	1952	15-20°	0°
Brooks	1949	20°	
Bunnell (Boyes)	1956 1970	20°	M.C. II in line=10°
Butler	1949	20-25°	0°
Campbell (Crenshaw)	1971	10-20°	
Carroll	1971	0-15° R.A.**	0-5°
Clayton	1965	0° (in R.A. slight palm. flexion)	thumb in line
Colonna	1944	20°	thumb in line
Crawford-Adams	1976	20°	0°
Danielsson	1963	15-20°	0°
Debeyre	1972	slight dorsiflexion	M.C. II
Dreisilker	1973	10-20°	M.C. II or III in line
Dunai	1959	slight	slight
Dupont	1968	0-15°	slight
Ely	1920	slight	0°
Evans	1955	0° (spastic pat.)	0°
Flatt	1963	20-30° (in R.A. bil. 0; en 10-20° palmar flexion)	
Goldner	1955	individual	
Jonas	1921	min. 30°	
Haddad	1967	10-15°	M.C. II in line
Hazewinkel	1962	20°	0°
Hindenach	1963	slight	slight
Horster	1977	20°	5°
Hussenstein	1964	30°	0°
J.A.M.A.	1958	30°	0°
Kanavel	1933	marked dorsiflexion	

Keatz	1965	0° (spastic pat.)	opp. thumb in line
McKenzie	1960	25°	
Law	1952	10-15°	
Liebolt	1938	25-30°	0°
Lisfranc***	1977	15-20°	M.C. III in line M.C. II: 5° radial
Linscheid	1968	0° R.A. to slight palm.	0-10°
Manetta	1975	25°	0°
Mannerfelt	1971 1972 1973	in R.A. variable: from 5° dorsal to 20° palm. flexion	0-10°
Merle d'Aubigné	1956	15-20°	0°
Meuli	1972	15-20°	M.C. II in line
Mikkelsen	1980	individual	M.C. II in line
Millender	1973	5-10°	0-10°
Papaioannou	1982	0°	M.C. II in line
Pipkin	1968	25°	
Post	1967	individual	
Rayan	1982	5-10°	0-10°
Rechnagel	1971	20-25°	slight
Reichelt	1973	15-25°	slight
Robinson	1952	20-30°	thumb in line+20° ulnar
Roux	1972	15-20°	slight
Schulitz	1967	20°	slight
Schwartz	1967	15°	0°
Skak	1982	slight (2nd hand in slight palm. flexion)	slight
Steindler	1918 1930 1940	slight	
Stjernwärd	1964	slight	slight
Thompson	1953	individual	
Tillman	1979	20°	5°
Thomas	1950	slight	0°
Vahvanen Kettunen	1979	slight to 0°	10 rad. M.C. II ulnar
Volz	1980	20°	individual
Watson Jones	1943	15-20°	thumb in line
Wachsmuth	1956	slight	M.C. II or M.C. III in line
Weigert	1975	10-15°	10°
White	1972	slight palm. (spastic pat.)	ulnar abduction
Wickstrom	1954	15-20°	5-10°

* i.e. in line with forearm

** in bil. cases: dominant hand: 10-15°, non-dominant hand: 0°

*** in bil. cases: dominant hand in slight dorsiflexion; non-dominant hand in slight palmar flexion

Dupoint and Vaino (1968) in unilateral arthrodesis fix the rheumatic wrist in a neutral position or in dorsiflexion to a maximum of 15°. In cases with affection of both wrists, the rule was to fix the functionally most important wrist in 0° and the other in 10° palmar flexion. The rheumatological surgeon's approach has to be different anyway because in most cases not just articular function is impaired but muscular function as well, and optimal strength of the affected limb is not required, which abolishes one argument in favour of dorsiflexion (according to Debeyre, 1972, the finger flexion force is decreased by 25% in the neutral position and by 50° in slight palmar flexion).
Dupont and Vaino accordingly emphasize that no single functionally optimal position exists, so that the position that affords optimal possibilities has to be determined for each individual patient, with occupational requirements, if any, taken into account.
Their publications, however, fail to mention the test methods to be used for this purpose.

Those performing wrist arthrodesis for neurological conditions – in spasticity and nervous lesions – as a rule advocate in spasms a neutral or palmar flexion position to prevent extension and resulting aggravated spasms of the finger flexors: Thompson (1953) and Goldner (1955) recommend, especially in cerebral palsy in which tendon transplantation is part of the treatment schedule, to perform wrist arthrodesis first, since otherwise severe muscular imbalance may ensue. It was found, however, that in severely spastic patients wrist arthrodesis was often indicated for cosmetic-psychological rather than for functional reasons.
When in a radial nerve injury the disengaged carpal flexors are transplanted to the finger extensor tendons, however, some degree of dorsiflexion is advisable, as also demonstrated by Post and Lavine (1967) in their EMG study (see also page 21).

II.3.2. Radioulnar abduction

Argumentation is also scarce where the lateral deviation position is concerned. Over one-half of the authors refrain from discussing it although they stipulate that M.C. III should be in line with the forearm in the anteroposterior projection. Liebolt (1938) and Schulitz (1967) advance as the only argument that in slight ulnar abduction flexion force is reduced especially in the first three fingers. Dupont (1968) refutes this by asserting that in slight ulnar abduction the flexor muscles pass across the wrist in a physiological-functional line, in which position they provide not less but more strength; Bunnell (1956) concurs.
Mannerfelt (1971) agrees with Shapiro (1968) and with Pahle and Raunio (1960) that in rheumatoid arthritis the metacarpus should definitely not be fixed in radial abduction, since this would lead to secondary ulnar drift.
One-third of the authors prefer to fix the wrist in slight ulnar abduction by

placing M.C. II in line with the forearm, which according to Bunnell (1956) and Malick (1972) amounts to a 10° ulnar abduction of the hand as a whole. Some 10% of authors go farther, however, and regard as optimal a position in which the opposed thumb is in line with the forearm in the dorsopalmar as well as in the lateral view. Robinson and Kayfetz (1952) state that this position equals 20° ulnar abduction.

II.3.3. Research into the functional position

As mentioned, it is interesting to note that all these functional positions are based on clinical experience rather than on functional anatomical experiments. Only a few authors: Post and Lavine (1967), Kraft and Detels (1972), Hazelton et al (1975), Volz et al (1980) and Pryce (1980) have attempted by using registration equipment to find out what carpal angle best preserves manual function.

Post and Lavine (1967) made their attempts by means of EMG registration and dynamometry, but only in patients with a radial nerve lesion or a neuropathy. In these conditions, the digital flexors are totally insufficient in hyperflexion of the wrist, but they can generate their force when tightened to some extent. In such cases the wrist should be fixed in a position that allows an optimal degree of stretch in the flexors (20°) and consequently, a firm grip by the fingers.

This position could be determined by EMG, although the value found did not always agree with the most forceful position determined by dynamometry. The optimal wrist positions found showed so much individual variability that no average functional position emerged. The authors, however, attach more importance to the EMG findings because they regard mechanical registration as too coarse for weaker strengths.

The other authors performed their investigations in normal healthy subjects, who were tested on the side of their dominant hand. Kraft and Detels (1972) studied grip strength and skill in performing various ADL tasks with the test subjects' wrists fixed in four different positions: 30° dorsiflexion, 15° dorsiflexion, 0° dorsiflexion and 15° palmar flexion. They found that where the ADL skills were concerned, the four positions were not distinctly different, but that where grip strength was concerned, the 15° palmar flexion position scored significantly lower than the other three, among which there was no clear difference.

Hazelton (1975) studied the influence of the angle of the wrist on finger flexion strength. He fixed the upper and lower arms of his test subjects in a cage and recorded grip strength in the following positions:

- in 0° dorsopalmar flexion and 0° radioulnar abduction
- in a palmar flexion position amounting to two-thirds of the subject's maximal palmar flexion (never exceeding 45°)
- in a dorsiflexion position amounting to two-thirds of the subject's maximal

dorsiflexion (never exceeding 60°)
- in 14° radial abduction and in 21° ulnar abduction.

In this investigation, maximal strength was recorded with the wrist in the ulnar abduction position and minimal strength in the palmar flexion position. Volz (1980) studied grip strength by means of EMG recording but had his test subjects perform 10 ADL tasks, as well. For this study, the wrists were immobilized in a number of positions. For the EMG study they were fixed in 40° and 20° dorsiflexion, in neutral position and in 20° and 40° palmar flexion. In this test, maximal strength could be recorded in 20° dorsiflexion. The ADL tasks were performed with the wrists splinted in 15° dorsiflexion, neutral position, 15° palmar flexion and 20° ulnar abduction. The results of these tests were best in the 15° dorsiflexion position and worst in the 20° ulnar abduction position.

Pryce (1980) refers to the unpublished Master's theses of Andersson (1965) and Skovly (1967), both of the University of Iowa, and to the data published by Kraft and Detels (1972) and Hazelton et al (1975) and asserts that these authors have never attempted to determine what carpal angle affords maximal grip strength. This prompted him to investigate finger flexor force in several carpal positions with variation of both ulnar abduction and dorsopalmar flexion, which resulted in nine different positions of the wrist, viz.:

0° ulnar abduction and 15° palmar flexion
0° ulnar abduction and 15° dorsiflexion
0° ulnar abduction and 15° dorsiflexion
15° ulnar abduction and 15° palmar flexion
15° ulnar abduction and 0° dorsopalmar flexion
15° ulnar abduction and 15° dorsiflexion
30° ulnar abduction and 15° palmar flexion
30° ulnar abduction and 0° dorsopalmar flexion
30° ulnar abduction and 15° dorsiflexion

In this study the body posture was also considered and even the breathing was monitored during the test to avoid strain during the effort (Valsalva manoeuvre).

The findings revealed that there were two groups of positions that differed significantly from each other, whereas within the groups different positions gave no significantly different performances.

The following positions, namely, scored significantly higher:

0° ulnar abduction and 15° dorsiflexion
15° ulnar abduction and 15° dorsiflexion
15° ulnar abduction and 0° dorsopalmar flexion
0° ulnar abduction and 0° dorsopalmar flexion.

The author adds that all test subjects mentioned that the positions with the 30° ulnar abduction were uncomfortable. Pryce, also, emphasizes in his discussion that the optimal wrist position should be determined prior to operation, particularly in patients whose occupations necessitate a strong grip.

The above review of the literature in itself allows the conclusion that no real *optimum* position of function exists. None of the authors, namely, have adequately considered that different manual functions require different positions in the wrist joint. Accordingly, the optimum position of function should not be interpreted as any absolute value, but at best as an approximation, a general average, with concessions to various manipulations, subject to individual requirements and possibilities. For this purpose, an ergonomical analysis would appear to be the method of choice but application of this method has so far not been reported in the literature.

CHAPTER III. EXTENT, INDICATIONS AND TECHNIQUES OF THE CARPAL ARTHRODESES

III.1. Extent of the arthrodesis region

In arthrodesis of the wrist joint, the connection between the forearm and the hand is immobilized.

In proportion to the extent of the arthrodesis, the kinetic chain of forearm and hand is impaired and the function of the carpal joint eliminated. The arthrodesis region may include the following articular levels:

the radiocarpal level
the carpal level and
the carpometacarpal level.

In the literature, the following grouping is made:

Radiocarpal arthrodesis: a fusion between the distal radius and the carpal bones. A special position is occupied by *partial radiocarpal arthrodesis,* consisting in fusion of the distal radius with the scaphoid and lunate bones; (Fig. 12A)

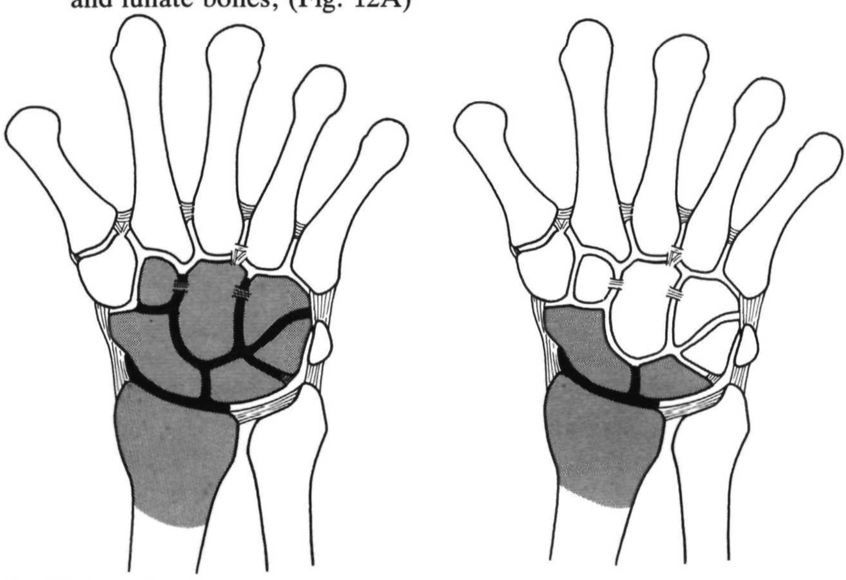


Fig. 12. A: radiocarpal arthrodesis (fusion between the radius and the carpal bones)

A[1]: partial radiocarpal arhtrodesis (fusion between the radius and the scaphoid and lunate bones)

Radiometacarpal arthrodesis: a combined ankylosis of the distal radius, carpal bones and one or more metacarpal bones; (Fig. 12B)

Intercarpal arthrodesis, creating fusion between several or all carpal bones (strictly anatomically speaking, this is only a partial arthrodesis of the wrist joint). (Fig. 12C)

Radiocarpal arthrodesis eliminates mobility in the radiocarpal joint and in the carpus but leaves the function of the carpometacarpal joints intact.
Radiometacarpal arthrodesis sacrifices radiocarpal and intercarpal functions and the functions of those carpometacarpal joints that are included in the fusion.
Both radiocarpal and radiometacarpal arthrodesis in principle leave the trapezium and the carpometacarpal joint of the thumb intact.
Intercarpal arthrodesis leaves some residual function between the forearm and the carpal block and also preserves the mobility in the carpometacarpal joints.

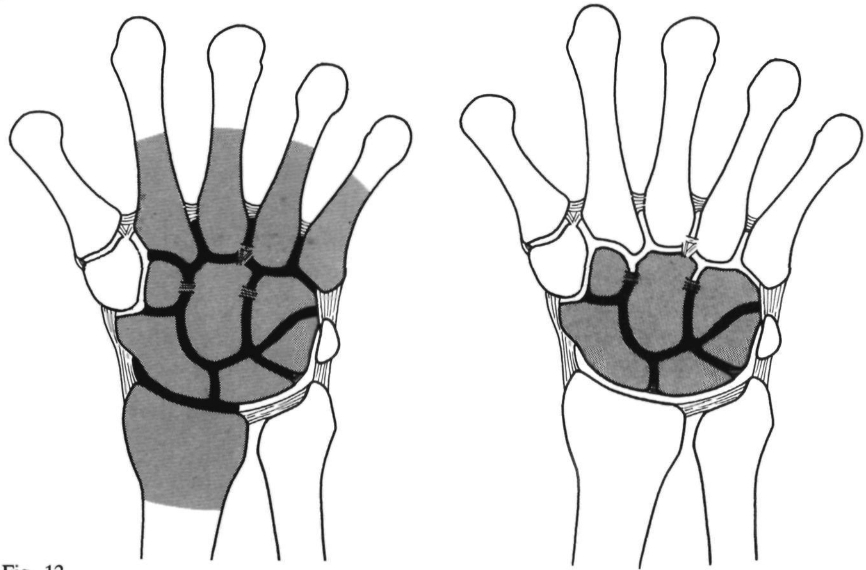


Fig. 12.

B: radiometacarpal arthrodesis (fusion of the radius, carpal bones and one or several metacarpal bones)

C: intercarpal arthrodesis (fusion of several carpal bones)

III.2. Indications

The literature (Liebolt, 1938) shows that the earliest wrist arthrodeses have been performed to treat tuberculous arthritis of the carpal region, in an attempt to improve upon resection of the wrist joint (Dietz, 1839) or even amputation (Dupuytren, 1846).
It provided a treatment which preserved the hand, sometimes with some residual function. Consequently, McNamara in 1888 wrote 'If we can secure ankylosis without excision, the patient will as a rule have a much better hand than he is likely to gain after the resection of the bone' (Liebolt, 1938). Carpal resection, namely, causes instability of the wrist joint.
With time, the need arose to stabilize the wrist for post-polio paralyses of the forearm and hand. The first wrist arthrodesis for a *flaccid* paralysis was carried out by Von Winiwarter (Max Lange, 1962).

Over the subsequent few decades, the range of indications was extended, but in recent years it has remained virtually unchanged.
Whereas initially wrist arthrodesis was performed mostly for tuberculosis, rheumatoid arthritis and paralyses, especially those due to poliomyelitis, the current range of indications is broader.
For the sake of convenience we have drawn up the following scheme to list the indications mentioned in the literature:

– Two conditions with *local* carpal pathology:

I. In the scaphoid bone: in case of pseudarthrosis or osteonecrosis (Preiser's disease, 1910)

II. In the lunate bone: in case of lunatomalacia (Kienböck's disease, 1910)

– A group with pathology of the *entire* carpus:

III. 'arthrosis-arthritis group'
- post-traumatic arthrosis
- infectious arthritis (non-specific/specific)
- systemic arthropathies:
  . rheumatoid arthritis
  . psoriasis
  . haemophilia
- articular contracture (e.g. due to scleroderma or injury)

– A group of conditions of *extracarpal* origin, but manifesting themselves in the wrist as well:

IV. 1. neuromuscular indications:
- congenital pareses of the upper limb (Erb/Klumpke)
- hemiplegias (spastic and flaccid)
- brachial plexus lesions
- radial nerve paralysis
- poliomyelitic pareses
- syringomyelia
- severe agonist/antagonist imbalance

2. lesions of the soft parts of the wrist and hand such as congenital deformities, growth abnormalities and post-traumatic and ischaemic contractures (e.g. Volkmann).

3. carpal defects requiring reconstruction, e.g. after injury or tumour operations.

The indications for the operation have remained the same through the years, viz. elimination of wrist pain, the sacrifice of (residual) mobility, the arrest of a pathological process and the achievement of a stable starting position with a view to tendon transfer etc. in pareses or for cosmetic reasons (Brooks, 1949; White, 1972 and House et al, 1976).

III.3. Surgical techniques

Even the older literature mentions besides resection also arthrodesis of articular surfaces which might or might not be affected by a pathological process – techniques using bone grafts to stimulate consolidation and to fill bone defects.

Dubar as early as 1897 reported wrist arthrodeses with use of canine bone grafts, but he found no followers.

Ely (1920) introduced the use of tibial autografts in 1910. Others followed suit: Spitzy (1914), Liebolt (1938), D. Thomas (1950), Brittain (1952), Hazewinkel (1962), F. Thomas (1965), Salenius (1965) and Schulitz (1967). Bone autografts were taken from other donor sites as well (Fig. 13):

- The *radial sliding graft* was used by Wittek (1914), Albee (1915), Liebolt (1938), Dunai et al (1959) and Clayton (1965), while it was used as an inverted graft by Herbert and Paillot (1950) and (according to Gill) by Stein (1958).
- A *proximal femur graft* was used by Scherb (1927).
- From the shaft of the *IIIrd metacarpal bone*, a graft was obtained by Kofmann (1935).
- Bone was taken from the *iliac crest* by Liebolt (1938), Abbott et al (1942), Brooks (1942), Butler (1949), White (1954), Campbell and Keokarn (1964), Clayton (1965), Haddad and Riordan (1967), Carrol and Dick (1971), Rechnagel (1971), Makin (1977), Kirschner and Schweigert (1977), Engel et al (1978) and Rayan (1982).
- The *distal ulna* was used by Smith-Petersen (1940), Brooks (1949), Seddon (1952), Cregan (1959), McKenzie (1960), Dupont and Vaino (1968), Holec (1978) and Vahvanen and Kettunen (1979)
- A *rib split lengthwise* was used by Colonna (1944) and Wickstrom (1954).

Liebolt as early as 1938 performed the arthrodesis in a bloodless field and he was the first to use bone autografts in the form of bone chips because he believed that chips would revive sooner and consequently cause earlier consolidation than one large graft.

Most authors used a dorsal approach to the wrist, but Smith-Peterson (1940) introduced a new approach. He first carried out a distal ulna resection (according to Darrach, 1915) and then approached the radiocarpal joint from the ulnar direction.

The resected part of the ulna was used as grafting material. The radiocarpal joint was denuded of cartilage and with the hand fixed in the desired (dorsiflexion) position, the distal radius and the carpus were split from the side, following which the shaped distal ulna or some other bone graft was driven into the resulting cleft. In 1946, Seddon introduced a modified version of the Smith-Peterson technique: instead of splitting the radius and carpus from the side, a wedged-shaped gutter was chiselled into both so that in 20° dorsiflexion the two gutters formed a lozenge-shaped cavity in which the shape-adjusted distal ulna was imbedded. This had the advantage that the circumference of the wrist did not increase (McKenzie, 1960).

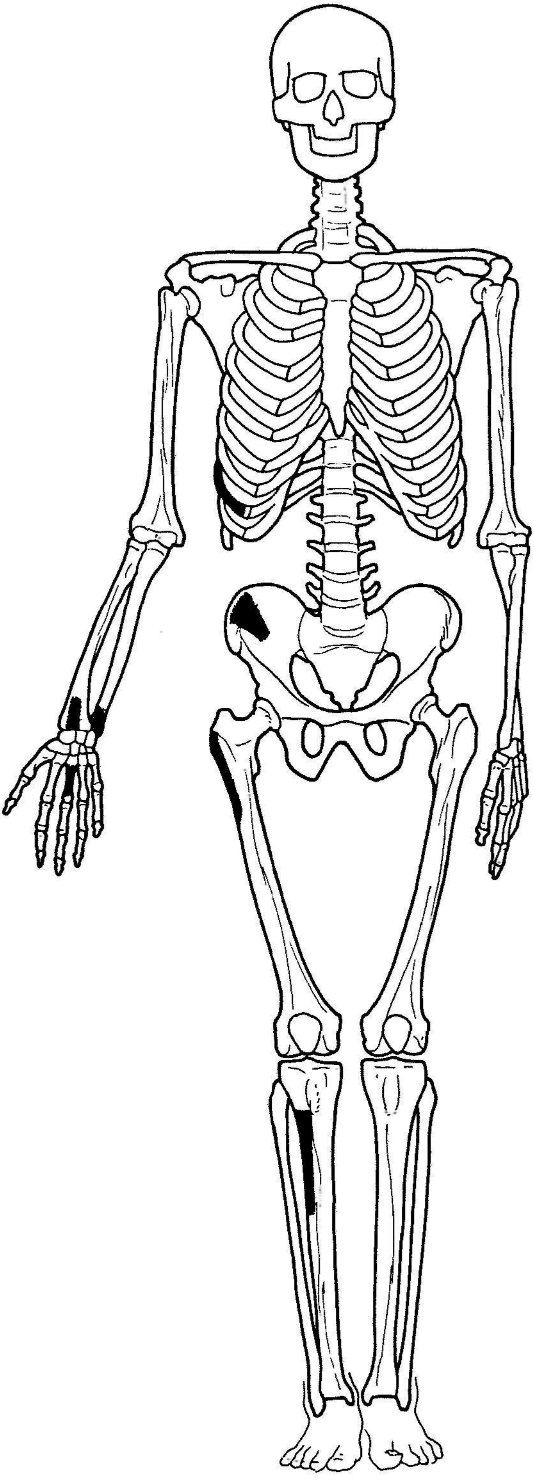


Fig. 13. Donor sites of bone autografts for wrist joint arthrodesis

Abbott in a paper of 1942 reviewed the techniques then known. He emphasized once more that spongy bone is to be preferred to cortical bone because of its faster revitalization and transformation and because it can be shaped.

All the techniques mentioned above concerned a radiocarpal or a radiometacarpal arthrodesis.

Intercarpal arthrodesis was introduced by Thornton in 1924, applied to a patient with capitate bone subluxation of long standing. This technique, and modified versions of it, have been used by many authors to this day (Sutro, 1946; Helfet, 1952; Gordon and King, 1961; Campbell and Keokarn, 1964; Graner et al, 1966; Schwartz, 1967; Peterson and Lipscomb, 1967; Scharitzer, 1968; Fenollosa and Valverde, 1970; Ricklin, 1970, 1974; Ashkenazi, 1972, 1976; Rosemeyer, 1973; Schmitt, 1973; Meine et al, 1974; Pfeiffer, 1974; Hörster et al, 1977; Duparc, 1978; Watson, 1980; Bertheussen, 1981 and Naett et al, 1981).
These authors restricted the indication to post-traumatic or degenerative pathology of the scaphoid and lunate bones.
Mostly these authors reported good results. Reichelt (1973), on the other hand, had the impression that after both radiocarpal and intercarpal arthrodesis problems persisted or arose which he attributed to a compensatory increase of mobility in the carpometacarpal joints. Since he did not observe these problems after radiometacarpal arthrodesis, he asserted that the metacarpal bones had to be included in the arthrodesis. Other authors also stated that regardless of the indication, the arthrodesis should include one or more metacarpal joints (Wittek, 1914; Colonna, 1944; Thomas, 1950; Brittain, 1952; Wickstrom, 1954; Witt, 1958; McKenzie, 1960; Hazewinkel, 1962; Clayton, 1965; Haddad and Riordan, 1967; Schulitz, 1967 and Carrol and Dick, 1971). Butler (1949, 1964) went even farther and extended the arthrodesis not only to the second and third but also to the fourth and fifth metacarpals, arguing that this would lead to less residual pain.
In recent years, however, several authors have pointed out that C.M.C. IV and V should definitely be *excluded* from the arthrodesis tract, so as to preserve mobility in these joints and consequently, the ability of the carpus to arch for certain grips (Reichelt, 1973; Kirschner, 1977; Narr, 1982 and Hörster, 1982).

In the last few decades radiocarpal and radiometacarpal arthrodeses have been carried out using osteosynthesis techniques with both internal and external fixation. The alleged advantage was shorter immobilization and accordingly, earlier functional training and rehabilitation. Robinson and Kayfetz (1952) after resection of the proximal carpal bones fixed the capitate to the radius with a screw. External fixation equipment was used by Dunai et al (1959). Forgon (1963) and Clayton (1965) in some cases combined the bone graft with a transfixing Steinmann pin. Hussenstein and Delaneau (1964) sharpened the radius and drove it into the carpus split in the manual plane (method of Evans, 1965); the whole was transfixed with Kirschner wires.

With all techniques listed above immobilization in plaster was also necessary and the only purpose of the introduction of fixation material was to preserve the desired position and sometimes to press the bony surfaces together.

Mannerfelt et al (1971, 1972, 1973) expanded Clayton's transfixation principle in such a way that essentially no additional immobilization in a cast was required any longer. After freshening the articular surfaces, from the third metacarpal they transfixed metacarpus and carpus to the radius, while to avoid rotation, one or two staples were inserted reaching from the radius to the distal carpal row.

This technique found many followers, mostly among rheumatological surgeons (Skak, 1982). Nicolle and Dickson (1979) modified this technique. They made a groove reaching from the base of M.C. III through the carpus into the distal radius and filled it with bone chips (of the carpal bones and sometimes of the resected distal ulna). The whole was then transfixed by a Steinmann pin. Papaioannou in 1982 reported his results with this technique.

Millender and Nalebuff (1973, 1975) stated that a transfixing Steinmann pin from carpus into radius, if necessary combined with one or several Kirschner wires through the metacarpal bones into the radius also gives enough stability to render after-treatment with a cast superfluous.

In recent years, the compression plate method is being used widely as appears from papers by Dreisilker and Koob (1973), Reichelt (1973), Schöllner (1973), Larsson (1974), Meuli (1974), Manetta and Tavani (1975), Bamert et al (1977), Kirschner (1977), Idzapanahea (1977), Narr (1982) and Hörster (1982). The 'Zuggurtung' principle (tension band wire method), of which Segmüller in 1974 reported good results, was never imitated, however.

III.3.1. Choice of the bone graft

The dispute pertaining to the type of bone to be used for transplantation has been going on for decades. As mentioned, Ely in 1910 introduced the one-piece tibial graft, while Liebolt in 1938 argued his preference for small autologous bone chips as follows:

Small chips revive faster and consequently are incorporated sooner than a larger fragment. During the period, namely, when the transplanted bone returns from inertia to vitality, absorption proceeds and the bone grows vulnerable and fragile. The incorporation of small chips precedes their complete revitalization. Diameter and volume of the bone graft determine the duration of the revitalization period, which is shorter in the case of small chips because the total contact surface is larger. Complete revitalization of small chips takes a few months, as against several years for a larger graft, Liebolt wrote.

Since that time, a number of authors have variously assessed a series of arguments pro and contra cancellous and cortical grafts.
Butler (1964) stated that the osteogenesis surrounding a bone graft is in fact a host reaction, with the inserted bone serving as the inductor. With spongy bone, he asserted, this reaction proceeded faster. Abbott et al (1942) agreed that cancellous bone is revascularized and revitalized by live bone more quickly than cortical bone. Also, it is slightly more plastic and its shape can more readily be adapted through uneven surfaces, facilitating handling. They add that the use of a one-piece tibial graft entails the risk of fracture of the donor bone. This might still occur as long as six months after implantation. For arthrodesis of the wrist, Butler regards a firm corticocancellous ilial graft as more reliable than ilial chips alone or a graft of cortical bone and periosteum, since the former would give faster consolidation.

The combination of cancellous and cortical bone, as found in the corticocancellous graft from the iliac crest, combines the advantages of both bone types: the fast incorporation of the cancellous bone and the relatively greater strength of the cortical bone.

III.3.2. Summary

Recapitulating, we may state that over the years, a number of techniques have been described which actually all derive from a few principles of carpal arthrodesis. The surgeon may choose from among the following possibilities:

- regarding extent:
  - intercarpal
  - radiocarpal
  - radiometacarpal
- regarding technique:
  - articular cartilage removed or left in situ; if desired, resection of the proximal carpal bones
- regarding fixation:
  - internal fixation: Kirschner wires, Rush nails, Steinmann pins, screws, plate osteosyntheses with or without compression;
  - external fixation: bar connector, plaster cast
- regarding the bone graft:
  - applied in one piece (inlay, onlay, or transfixing bone plug), as chips or combined; in the form of: cortical bone grafts, corticocancellous bone grafts, cancellous bone chips.

All possible combinations of the above-named possibilities have been described in the literature. This may show that wrist arthrodesis is a complicated procedure, for which no single technique as yet may be regarded as superior and consequently as the procedure of choice.

III.4. Current alternatives

In order to reduce impairment of carpal function, various authors have tried other forms of treatment, especially for rheumatoid arthritis, because in this disease the lesion is often bilateral and adjoining articulations are frequently also involved.

In this respect, mention should certainly be made of *synovectomy* which may or may not be followed by temporary reposition and immobilization by means of transfixation with Kirschner wires (Lipscomb, 1965; Straub and Ranawatt, 1969) or a Steinmann pin (Hooper, 1972).

There have also been reports of *interposition-arthroplasties* with either the extensor retinaculum (Stellbrink and Tillman, 1973, 1976; Allende, 1973), or costal perichondrium (Pastacaldi and Engkvist, 1979), sometimes with stabilization by means of a palmar shelf created from the distal radius (Albright, 1970; Brumsfield, 1979). Quick and Wilhelm (1980) were the first to apply the tendon interposition principle of Froimson (1970) to the scaphoid and lunate bones, using a tendon autograft. Resection-interposition arthroplasties are frequently followed by greater functional impairment, especially if maintenance of the position has required transfixation.

A technique that goes one step farther than resection-interposition arthroplasties with autologous tissue is *interposition of foreign material,* which may consist of silicon rubber implants inserted locally into the carpus (Wilhelm et al, 1979), but also in prostheses specially designed to replace the scaphoid or lunate bone, as developed by Swanson (1973) and also used by Lichtmann et al (1977) and Gadzali and Ghori (1979).

Regarding of the carpus as a whole, we may mention the silicon rubber disc (Jackson and Simpson, 1979), silicone hinge prostheses (Swanson, 1973, 1977 and 1979; Schwägerl, 1979 and Goodman et al, 1980) and even multiaxial endoprostheses to be cemented in (Meuli, 1973, 1975, 1977 and 1980; Beckenbaugh et al, 1976; Gschwend et al, 1973, 1977; Volz, 1976, 1977 and 1980); all these authors have published positive results.

In general, the selection criteria applied by the last-mentioned authors are:

- Adequate muscular balance, or the possibility to restore it
- Good local conditions of skin, neurovascular system and bone bed
- Residual rehabilitation capacities of the patient.

'The hand, under the control of the intellect, has enabled man to reduce his environment to basic components that can be controlled by switches, tools, buttons, zippers, wheels, etc '
Frank T Hazelton 1975

PART II

CHAPTER IV. DATA REGARDING THE CLINICAL MATERIAL

IV.1. Introduction

A follow-up study was carried out to assess the results of arthrodesis of the wrist joint.

An attempt will be made on the basis of the findings to establish criteria which a wrist arthrodesis should fulfil. The follow-up included those patients who had undergone a wrist arthrodesis in the period 1961 to 1974 inclusive.

The follow-up consisted of three parts: a clinical, a radiological and an ergonomic study.

The clinical follow-up consisted of physical examination of the local and regional conditions of the wrist and donor site.

The radiological evaluation concerned the extent of the intervention, the radiological aspect of the bony structures of the arthrodesis region, the position of the hand in relation to the forearm and its changes, if any.

The ergonomic study included an anamnestic inventory of specific complaints regarding the manual function both pre- and postoperatively, as well as determination of residual manual function in various test-setups.

The data and findings obtained were processed and compared with each other, including a comparison of the overall pre- and postoperative situations, to arrive at a definitive evaluation of the residual function of the hand.

IV.2. General data

IV.2.1. Number of patients

Out of 73 patients subjected to a arthrodesis of the wrist joint in the period 1961 to 1974 inclusive, 65 were included in this retrospective study. Eight patients could not be followed up for the following reasons:

- deceased: 1
- failed to respond: 3
- returned to Yugoslavia: 1
- reoperated shortly before: 1
- no data available: 2.

One patient had had a bilateral operation, so that the total number of wrist arthrodeses examined amounted to 66.

The 65 patients had been operated in Nijmegen in the Departments of Orthopaedics of the St. Maartens Clinic (30 patients) and of the St. Radboud Hospital (35 patients, 36 wrists).

The follow-up study was carried out in 1976, one to 14 years (average 6 years) postoperatively.

IV.2.2. Classification by indication

The classification based on the indications is described on page 26. Application of this classification to our patients yielded the following numbers per group:

The two groups with local carpal pathology:

I. the '*scaphoid group*', 12 cases

II. the '*lunate bone group*', 18 cases

The group with involvement of the entire carpus:

III. the '*arthrosis/arthritis group*', 18 cases.

The group in which the underlying disease was localized outside the wrist, but had involved the wrist as well; since in our series this group consisted exclusively of neurological lesions, we named it simply;

IV. the '*neurological group*', 18 cases.

The lesions in the four groups are listed in detail in the table below:

TABLE 2

group I.	Scaphoid group:		
	scaphoid pseudarthrosis		12
group II.	Lunate bone group:		
	lunatomalacia (Kienböck's disease, 1910, 1980)	17	
	lunate bone necrosis after fracture	1	
			18
group III.	Arthrosis/arthritis group:		
	arthrosis (posttraumatic)	8	
	psoriatic arthropathy	3	
	rheumatoid arthritis	2	
	haemophiliac arthropathy	1	
	arthritis of unknown origin	1	
	scleroderma	1	
	posttraumatic contracture	1	
	tuberculosis	1	
			18
group IV.	Neurological group:		
	hemiplegia	4	
	posttraumatic spastic hemiplegia	1	
	hemiplegia	1	
	brachial plexus lesion	1	
	radial nerve lesion	4	
	nervous lesion with forearm defect loc. at carpal jointed	2	
	post-polio paresis	3	
	Erb's paralysis	2	
			18

IV.2.3. General preoperative data

For the general preoperative data, the preoperative local and regional state, the reader is referred to the relating tables with the corresponding remarks.

The table of the general preoperative data (table 3) lists by indication group:

1: the male-female ratio

2: the dominant-non-dominant hand ratio
(The dominant hand is the hand preferentially used in voluntary motor acts, in other words, the *right* hand in *right* handed persons and vice versa).

3: The right-left ratio

4: the age in years at the time of onset of the disorder

5: the age in years at the time of operation

6: The interval in months between the onset of the disorder and the operation.

TABLE 3

General preoperative data

	group I (n=12)	*group II* (n=18)	*group III* (n=18)	*group IV* (n=18)	*total* (total =66)
1. male : female	11 : 1	15 : 3	15 : 3	15 : 3	56 : 10
2. dominant: non-dominant hand	7 : 5	17 : 1*	11 : 7	8 : 10	43 : 23
3. right : left	7 : 5	16 : 2	9 : 9	11 : 7	43 : 23
4. age at time of onset (median)	18 - 59 (32 yr)	14 - 40 (28 yr)	5 - 56 (32 yr)	0 - 43 (4 yr)	0 - 59 (28 yr)
5. average age in years at operation	34½	30½	41½	18½	33½ (11-60 yr)
6. average interval in months between onset and operation	±35	±35	70	132	42½ (6-656mnth)

* this patient was ambidextrous

Regarding the right-left and the dominant-non-dominant hand ratios, the following should be noted:

It is only in group II, the 'lunate bone group', that the right-left ratio showed a strong predilection for the right: 16 : 2. As regards dominance, it was found that of this group, 18 patients had been operated on their dominant hand, while the 18th was ambidextrous, so that in actual fact all lunatomalacia patients had been operated on their dominant side.

The long interval between the onset of the condition and the time of operation in patients of group IV is explained by the fact that in congenital neurological lesions these definitive operations as a rule are postponed in connection with growth.

IV.2.4. Preoperative local and regional states

In regard to the data on preoperative local and regional states, it should be kept in mind that these data have been obtained from clinical files of two different institutes and that the facts have been recorded by a number of colleagues with variable accuracy.

Where function had not been quantified, it had as a rule been described.In order to enable processing of the clinical data in spite of this shortcoming, a rather rough system of classification of information on functional impairment was adopted.

For those patients whose carpal function had been quantified, the following method was used:

On the basis of the J.A.M.A. (1958) impairment scale, which ascribes 70% of total wrist function to dorsopalmar flexion mobility and 30% to radioulnar abduction, we calculated for each patient the proportion of loss of total dorsopalmar mobility (max. 70% of wrist mobility) and the proportion of loss of radioulnar mobility (max. 30% of wrist mobility).

The addition of the values found provided the proportion of impairment of wrist function, in which connection it should be kept in mind that various functions are combined. These degrees of impairment were classified as follows:

0% impairment: none (normal)
1- 30% impairment: slight impairment
31- 60% impairment: moderate impairment
61- 90% impairment: severe impairment
91-100% impairment: a-functional

For instance, for a patient with the following functions:

palmar flexion 30°
dorsiflexion 20°
ulnar abduction 15°
radial abduction 10°

The various functional impairments of the wrist per function amount to 20°, 20°, 10° and 6,7°, respectively, or a total of 56,7% impairment, so that this patient will be classified as moderately impaired (cf. evaluation table, Appendix I).

Those patients whose function had been recorded verbally, were classified within this system according to the judgement of the orthopaedist in charge of the follow-up. *For instance, a patient whose carpal function was described as mildly impaired, was equated with those with 1-30% functional impairment = 'slight impairment', and one with greatly impaired carpal function was included with the group with 61-90% impairment and accordingly classified as 'severely impaired'.*

Identical systems were applied to classify pronation and supination mobility, elbow and shoulder function.
It will be clear that this data classification system is less than exact, with a risk of inaccuracy. In view of the quality of the recording in the clinical files, however, we had to make the best of it.

The patient files yielded the following overall data in regard to local and regional states:

1 - impairment of wrist function: normal, slight, moderate, severe, a-functional
2 - capsular and synovial swelling
3 - prominence or subluxation of the distal ulna
4 - (sub)luxation of the entire wrist joint
5 - mobility and function of hand and fingers: normal, partially impaired or reduced, none
6 - grip strength
7 - sensibility
8 - impairment of pronation and supination: normal, slight, moderate, severe, afunctional
9 - impairment of elbow function: normal, slight, moderate, severe, afunctional
10 - function of muscles serving the elbow joint: normal, partially impaired or reduced, none
11 - impairment of shoulder function: normal, slight, moderate, severe, afunctional
12 - function of muscles serving the shoulder joint: normal, partially impaired or reduced, none.

TABLE 4

Pre-operative local state

	group I	*group II*	*group III*	*group IV*	*total*
1. impairment of wrist function					
none (0%)	–	–	–	–	–
slight (0-30%)	5	5	2	–	12
moderate (31-60%)	5	11	5	2	23
severe (61-90%)	2	2	4	7	15
a-functional (91-100%)	–	–	7	9	16

TABLE 4 (Cont.)

Pre-operative Local State

	group I	*group II*	*group III*	*group IV*	*total*
2. *capsular/synovial swelling*	3	6	6	–	15
3. *prom./sublux. dist. ulna*	–	–	4	–	4
4. *(sub)lux. entire wrist*	–	–	7	3	10
5. *mobility and function of hand and fingers*					
normal	11	18	11	–	40
partially impaired or reduced	1	–	7	16	24
impossible	–	–	–	2	2
6. *grip strength*					
normal	–	4	1	1	6
partially impaired or reduced	12	14	16	14	56
impossible	–	–	1	3	4
7. *impaired sensibility (in the hand)*	1	–	1	6	8

Pre-operative regional state

	group I	*group II*	*group III*	*group IV*	*total*
8. *impairment of pronation-supination*					
none (0%)	6	13	9	1	29
slight (1-30%)	6	5	2	4	17
moderate (31-60%)	–	–	2	2	4
severe (61-90%)	–	–	3	6	9
a-functional (91-100%)	–	–	2	5	7
9. *impairment of elbow function*					
none (0%)	12	18	15	5	50
slight (0-30%)	–	–	3	5	8
moderate (31-60%)	–	–	–	1	1
severe (61-90%)	–	–	–	2	2
a-functional (91-100%)	–	–	–	5	5
10. *muscles serving elbow joint*					
normal	12	18	17	3	50
partially impaired or reduced	–	–	1	13	14
impossible	–	–	–	2	2

	group I	group II	group III	group IV	total
11. impairment of shoulder function					
none (0%)	12	18	17	7	54
slight (0-30%)	–	–	1	2	3
moderate (31-60%)	–	–	–	1	1
severe (61-90%)	–	–	–	5	5
a-functional (91-100%)	–	–	–	3	3
12. muscles serving the shoulder					
normal	12	18	18	7	55
partially impaired or reduced	–	–	–	9	9
impossible	–	–	–	2	2

N.B. In all groups, most patients during the period immediately preceding operation had been handicapped by their condition to such an extent that they were hardly or not able to function in their occupation or profession.

In regard to preoperative motor function and mobility of the hand and fingers: capacities determined were flexion, extension, opposition, reposition, spreading and adduction, classified as normal, partially impaired or reduced and impossible.
This muscular function was unimpaired in groups I and II, partially impaired or reduced in one-third of the cases of group III and impaired in all cases of group IV.
Grip strength was reduced in 60 patients, while in three neurological patients it was totally absent.
In regard to preoperative sensibility:
One patient with pseudarthrosis of the scaphoid and one with post-traumatic arthrosis had pre-existent hypaesthesia in the dorsal region of the hand. Impaired sensibility in the same region was also seen in one-third of the patients of group IV.

Regional state

Shoulder and elbow functions were evaluated using the same impairment scale as used for wrist function (i.e. the J.A.M.A. impairment scale, see page 36). As the table shows, the *function* of shoulder and elbow joints was impaired only in groups III and IV. Virtually the same applied to the *muscular strength* controlling the function of these joints.

IV.3. Description of the surgical techniques applied

IV.3.1. Introduction

The many methods used to perform wrist arthrodesis have been surveyed above, in the historical review.
Since the patients included in this study had mostly been treated by means of two different techniques, viz. the Brittain-Ely (1952-1920) and the Butler (1949) method, these will be described here in greater detail. The operation can be divided into a wrist phase and a donor bone phase.

IV.3.2. The wrist phase - general

As a general rule the operation was performed in general anaesthesia, with the blood expelled from the arm by means of Esmarch's bandages.
First, if necessary, to prevent the distal ulna from being wedged into the carpus, thereby impairing pronation/supination mobility, a distal ulna resection was carried out through a separate ulnar incision, according to the method of Darrach (1915).
Then, a straight or curved incision, 10-12 cm long, was made in the dorsum of the wrist over Lister's tubercle (a bony prominence on the distal, dorsal aspect of the radius that separates the tendons of the m. extensor carpi radialis longus and brevis from the extensor pollicis brevis tendon). Mostly the incision extended from approx. 8 cm proximal of the radiocarpal joint to 1-2 cm beyond the base of the IIIrd metacarpal bone.
After spreading of the skin and subcutaneous layer, the dorsal carpal ligament was reached, with the several fibrous canals separating the tendon sheaths. This ligament was incised lengthwise together with the periosteum over Lister's tubercle, and the periosteum of the distal dorsal portion of the radius was removed, taking care not to damage the tendon sheaths of the extensor pollicis longus, the extensores carpi radialis longus and brevis and extensor digitorum communis muscles. The extensor digitorum communis tendons were kept to the ulnar, the extensor pollicis longus tendon to the radial side.
The extensor carpi radialis longus and brevis tendons were either detached from their insertions or held on the radial side. Thus, the dorsal aspects of the radiocarpal and intercarpal joints were exposed. The radiocarpal joint was opened by incising the capsule and the dorsal radiocarpal ligaments along the edge of the radial articular surface. Palmar flexion then created enough space to remove the cartilage from the distal radius and from the opposing aspects of the scaphoid and lunate bones.
The intercarpal articular clefts could be exposed in a body by removing a flat layer with the osteotome, after which the dorsal capsular ligaments and a thin cortical layer could be lifted together from the dorsal surface of the scaphoid, lunate and capitate bones. If necessary, the cartilage is removed from the small articular surfaces.

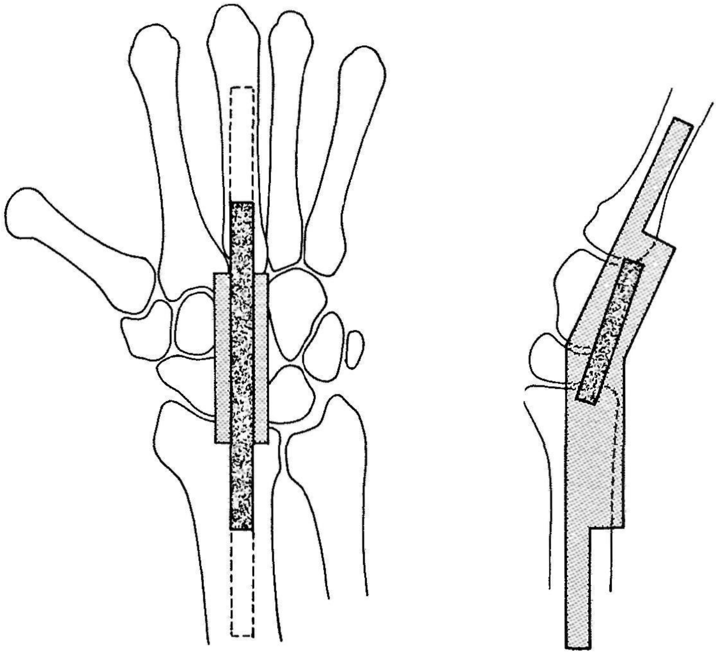
Radiocarpally, as much bone was removed as required to bring the carpus on a level with the distal radius. If the operation is concluded at this stage, and the bony surfaces of the radius and carpus are allowed to fuse, the operation is a socalled *(wedge) resection arthrodesis*. (Depending on the extent of resection, however, this is a partial, radiocarpal arthrodesis.)

IV.3.2.1. The Brittain-Ely method

With the Brittain-Ely method (Figs 14 and 24) after exposing the dorsal carpus, a gutter, 1.75 cm wide is created, beginning in the third metacarpal and continuing along the carpal bones to 2.5 cm into the distal radius (Brittain himself left the remaining carpal cartilage in situ). From the gutter created, a narrow chisel was then introduced into the medullary cavities of MC III and the radius to a depth of 2.5 cm. Some spongy bone was then placed on the floor of the gutter, following which a tibial bone graft, with stepped ends and a central curvature of approx 15° was inserted 2.5 cm deep into the distal radial medullary cavity. Then, by traction on the fingers, the third metacarpal could be levered over the distal end of the introduced tibial graft. If necessary, the distal portion of the graft would be shortened slightly. Then, by reducing the traction on the hand, MC III could be moved over the end of the graft, which was fixed in situ. The Brittain-Ely technique included making two narrow slits on either side of the central portion of the graft, i.e. from the radius to the metacarpals, which were filled with the bone fragments sawn from the ends of the graft (Fig. 14A).
(Brittain initially omitted this, sticking more closely to Ely's technique (Fig. 14B), but was persuaded to include it after fractures of the graft occurred in his own patients as well as in those of colleagues who followed his technique.) Then, cancellous bone from the tibial head was pressed into the remaining clefts. The periosteal layer from the donor bone might be sutured to cover the area, after which the wound was closed in layers, with a drain left in situ if desired.
As mentioned, Brittain's technique was an extended version of the method described as early as 1920 by Ely, who created a slit measuring 5 × 0.5 cm, from the base of MC III through the carpal bones and 1 cm into the distal radius; a rectangular tibial graft measuring 4 × 0.5 cm was inserted into this, and wedged into the wrist by dorsiflexion of the hand (Fig. 14B).

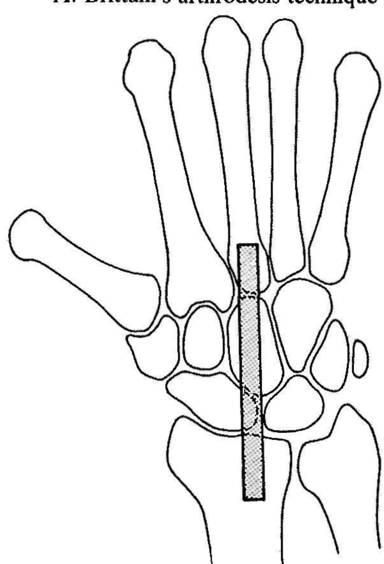
IV.3.2.2. The tibial donor bone phase

In this phase, with or without tourniquet ischaemia of the area, the anteromedial cortex of the tibia was exposed and a rectangular flap of periosteum measuring 12.5 × 2 cm removed in toto. Then, a cortical graft was sawn out, approx 1.5 cm wide and some 5 cm longer than the gutter made in the carpal region. In order to prevent fracturing of the graft during the sawing-out, most surgeons followed Brittain's advice and first removed a rectangular piece of bone, subsequently adjusting it to the desired dorsal



Dorsal view Lateral view

Fig. 14.
A: Brittain's arthrodesis technique (Brittain, 1952)



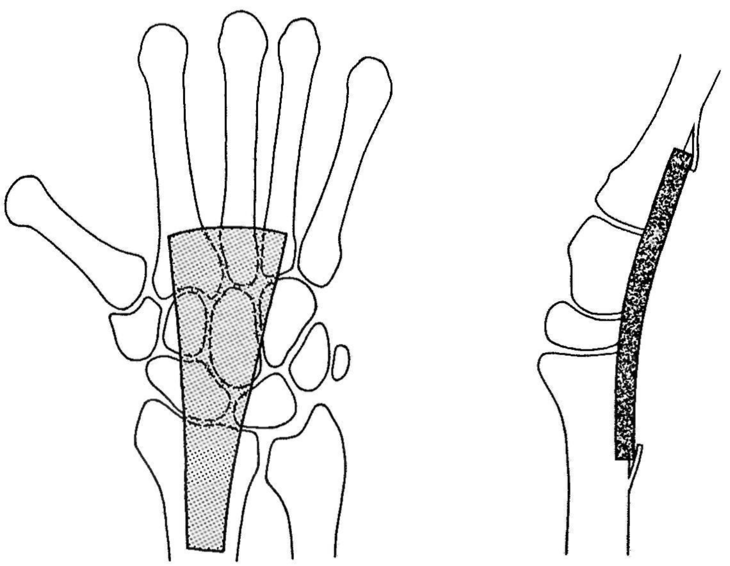
Dorsal view

B: Ely's arthrodesis technique (Ely, 1920) flexion shape with a central curvature of 15°. The distal ends were then narrowed stepwise, the narrowing amounting to one-half of the width of the graft on the radial side and to one-third on the metacarpal side. Thus, the two ends of the graft could be introduced into the respective medullary cavities to serve as locking pins. As mentioned before, the fragments removed from the ends could subsequently be inserted into the carpal region, on either side of the tibial graft, for extra strength.

IV.3.2.3. The Butler method

With the Butler method (Figs 15 and 25) a thin cortical layer was lifted from the distal radius using an osteotome, and beneath it, a deep bed was created that continued into the carpal bones and further into the bases of MC II and III (and if necessary, of MC IV and V as well); in the last-mentioned bones, an overhanging dorsal cortical wall was also created. In the middle of the carpus and in the base of MC III, the bone gutter was slightly deeper than at the edges, so that the palm of the hand instead of being flattened remained slightly concave, giving better grip function. Care was taken during this phase not to damage the radioulnar joint, to avoid later impairment of pronation and supination mobility. The bone bed thus created was filled with a fan-shaped graft of corticocancellous iliac bone that naturally possesses the necessary qualities as regards shape and structure.

The graft was wedged firmly into place by dorsiflecting the wrist and hand under traction, over approx 20°. Then again, closure of the wound by layers, with a wound drain left in situ if desired.



Dorsal view — Lateral view

Fig. 15. Butler's arthrodesis technique (Butler, 1949), which allows if desired the inclusion not only of CMC II and III but also CMC IV and V in the arthrodesis tract

IV.3.2.4. The iliac crest donor bone phase

Here, a skin incision, some 6 to 8 cm long was made along the lateral edge of the iliac crest. For this incision, the skin was tightened slightly in the cranial direction so that later, the cutaneous scar would be localized below the edge of the crest. After severing the subcutaneous layer, the borderline between the m. obliquus abdominis externus and m. tensor fasciae latae and m. gluteus medius appeared as a white line, where the muscular fasciae become the periosteum. The periosteum was incised along this line and using a raspatory, lifted from the internal and external layers of the iliac ala. Then, using slightly curved chisels or osteotomes, a corticocancellous graft, some 3 cm wide and some 8 cm long, was detached from the internal layer of the iliac bone and modelled to fit. After haemostasis, the periosteal edges were readapted using strong nylon sutures, following which the subcutaneous layer and skin were closed, a drain being left in situ if desired.

Table 5 concisely shows the differences between the Brittain-Ely method and the Butler technique:

TABLE 5

	Brittain-Ely	**Butler**
graft bed	narrow and deep	wide and superficial
number of CMC joints involved	1	2-4
bone graft	cortical (tibia graft)	corticocancellous (ilium graft)

IV.4. Peroperative and postoperative data

These data have also been arranged by indication group and for the total series (see Table 6).

Per group, this table lists:

1. the extent of the arthrodesis tract
   - wedge resection (= partial radiocarpal)
   - radiocarpal
   - radiometacarpal
2. distal ulnar resection, if performed
3. combination with synovectomy
4. the bone graft classified by donor site:
   - radius
   - tibia
   - ilium
5. the use of the bone graft as onlay or inlay graft
6. additional osteosyntheses

7. duration of tourniquet ischaemia (classified by technique and extent)
8. postoperative immobilization: upper arm or forearm cast
9. postoperative hospital stay in days
10. duration of postoperative immobilization in days

TABLE 6

Per- and postoperative data

	group I (n=12)	*group II* (n=18)	*group III* (n=18)	*group IV* (n=18)	*total* (n=66)
1 extent					
– wedge resection	–	–	3	1	4
– radiocarpal	–	1	3	4	8
– radiometacarpal	12	17	12	13	54
2 distal ulna resection	–	1	5	1	7
3 synovectomy	–	–	4	–	4
4 donor sites					
– none (in wedge resection)	–	–	3	1	4
– radius	–	–	2rc	1rc	3
– tibia	6rmc	7rmc	5rmc	13^{1rc}_{12rmc}	31
– ilium	6rmc	11^{1rc}_{10rmc}	8^{1rc}_{7rmc}	3^{2rc}_{1rmc}	28
5 inlay onlay graft	12 0	18 0	14 1*	17 0	62 1*
6 additional osteo-synthesis	–	2	4	1	7
7 duration of tourniquet ischaemia in min	60-130 (82½)	35-125 (81¼)	45-110 (80)	55-120 (88⅓)	35-130 (82½)
– wedge resection					(55)
– radiocarpal					(75½)
– radiometacarpal					(87½)
8 postoperative immo-bilization upper arm-forearm cast	9 3	17 1	7 11	15 3	48 18
9 duration postop hosp in days	9-23 (12)	6-26 (14 8)	3-33 (13 5)	9-34 (16 5)	3-34 (14 6)
10 duration postop immobili-zation or consolidation time in days	93-365 (132½)	77-320 (105½)	54-198 (96½)	70-211 (126½)	54-365 (118)

N B The figures in brackets are the median values of the durations in question
* iliac graft

IV.4.1. Postoperative management

From the methods of after-treatment, the following policy lines emerge.

After wound closure, most patients were fitted with a padded circular upper arm cast, which extended beyond the MCP joints (so that both joints on either side of the wrist were immobilized as well. In 18 cases, 11 of them from group III, primary after-treatment consisted in a forearm cast). The hand was suspended high and, if necessary, anti-inflammatory, anti-oedematous medication was administered.

In case of badly swollen fingers or other signs of compression or congestion, the cast was split.

If necessary, the cast was replaced and the wound inspected after 10-14 days, with X-ray control if desired, and removal of the stitches.

The replacement cast had a thin padding and was made to fit closely.

In principle, the patient was then discharged. In most cases, 3 months' immobilization was prescribed, with as a rule an upper arm cast for 2 to 6 weeks which was subsequently shortened to a forearm cast. All casts left the thumb completely free.

IV.4.2. Complications

Peroperative complications:

These occurred 12 times (= 18%), viz.:

- graft fracture 4 times (1 x ilium, 3 x tibia)
- problems with excision of graft 4 times (1 x radius, 1 x ilium, 2 x tibia)
- radial fracture twice
- metacarpal fracture twice.

Postoperative complications:

These consisted in disturbance of the healing of the wrist wound: 3 times (2 superficial infections, 1 deep infection) and complications at the donor site, observed at 16 of the 62 donor sites (25.8%). These complications showed no correlation with any particular indication.

Classified by donor sites, the following problems were involved:

- after 31 tibial transfers, we observed:
  6 fractures (19.4%)
  1 (early) infection (3.2%)
  3 sensibility disorders (9.7%)
- after 28 iliac transfers, we observed:
  1 (late) infection (3.6%)
  4 sensibility disorders (13.9%)
  1 haemorrhage (3.6%).

In most cases, the donor site continued to cause discomfort until the time of removal of the cast.

IV.5. Out-patient after-treatment

According to the records, out-patient control examinations initially consis-

ted only in inspection of the cast and X-ray control. When the X-ray findings suggested consolidation, the cast was removed and the arthrodesis evaluated clinically and radiologically. If it was then considered necessary to continue the immobilization, this was always done by means of a forearm cast.
The duration of immobilization ranged from 54 to 365 days with a median of 118 days. In this respect there were no significant differences between the indication groups.

Degree of consolidation after removal of the cast

As early as 1905, Hoffa defined 'Ankylosen' as 'diejenigen Zustände in denen zwei oder mehrere knöcherne Gelenkenden durch zwischen- oder übergelagertes Gewebe unverschiebbar mit einander vereinigt sind' (Conditions in which two or more bones of a joint are immovably united by inter- or superimposed tissue). If the interposed tissue is fibrous, the ankylosis might be called fibrous, while in case of bony union, he speaks of a bony ankylosis. Similarly, Jones (1921) regarded immobile union of bones in a joint as a condition of 'a true ankylosis'. Depending on the nature of the tissue connecting the bones - bony or fibrous - he also used the terms 'bony ankylosis' and 'fibrous ankylosis', respectively. Clearly, the latter can only be distinguished radiologically.
On this basis, a wrist joint clinically judged immobile may be called *ankylotic*, whereas an arthrodesis tract with mobility (which in the X-ray will show no bony consolidation) will be called a *pseudarthrosis*.
The above results in the following classification:

- a wrist joint clinically judged *ankylotic, with* bony union: the arthrodesis is *consolidated* (Fig. 16A)

- a wrist joint clinically judged as *ankylotic, without* bony union: there exists a *fibrous ankylosis* (Fig. 16B)

- a wrist joint clinically judged *mobile, without* bony union: there exists a *pseudarthrosis* (Fig. 16C)

There remains the possibility that the wrist joint is clinically judged to be still mobile, whereas the X-ray suggests bony union. In this case, either the clinical or the radiological examination has of necessity been performed or interpreted incorrectly.

Classified according to the above criteria, on termination of immobilization (at the latest one year postoperatively), 49 wrist joints were found consolidated, while 3 were fibrous-ankylotic and 14, pseudarthrotic. Of these 14, 8 proved to have been operated with a tibial graft and 6 with an iliac graft. In other words, pseudarthrosis occurred with 8 out of *31* tibial grafts and 6 out of *28* iliac grafts. Table 7 shows the causes and group distribution:

Fig. 16. The degree of consolidation (anteroposterior projection)

A: a patient with a consolidated arthrodesis

B: a patient with a fibrous-ankylotic wrist joint

C: a patient with a pseudarthrotic wrist joint (A and B *can* be distinguished radiologically but *not* clinically, B and C *can* be distinguished clinically but *not* radiologically). N.B.: In B as well as in C the interruption of the bony continuity is localized at the carpometacarpal level.

Fig. 16. The degree of consolidation (lateral projection)

A: a patient with a consolidated arthrodesis

B: a patient with a fibrous-ankylotic wrist joint

C: a patient with a pseudarthrotic wrist joint

TABLE 7

Pseudarthroses after removal of cast

	no fusion	*fracture of graft*	*sclerosis of graft*	*absorption of graft*	*total*
Group I	1	3	1	2	7
Group II	3	–	–	1	4
Group III	–	–	–	2	2
Group IV	–	1	–	–	1
	4	4	1	5	14

Five pseudarthroses were reoperated: this led to consolidation in four cases while the fifth wrist remained pseudarthrotic after revision operations.
The following surgical interventions have been carried out in addition to the wrist arthrodesis:

- flattening of graft 3
- tendon transfer 5
- shoulder arthrosis 1 (in group IV)
- flexor release 1
- distal ulnar resection 1 (in group II)

Dystrophy was observed in 11 patients. Five of them received physiotherapy. The total number of patients receiving physiotherapy was 17. Ergotherapy was administered to only 5 patients (4 neurological patients and 1 patient with tuberculosis).

CHAPTER V. THE CLINICAL FOLLOW-UP EXAMINATION OF THE PATIENTS

Sixty-five patients (with 66 operated wrist joints) responded to invitations for this follow-up.

This control examination, performed by the author, included:

1. anamnesis
2. orthopaedic examination of the local and regional states (including the donor site)
3. X-ray examination of the wrist
4. ergonomic examination*

V.1. Anamnestic evaluation

This anamnesis concerned the follow-up period, i.e. the period after the arthrodesis. Specific questions were asked concerning the following factors that affected the use of the hand:

- pain
- strength reduction
- the (in)capacity to grasp an object firmly
- sensations of instability, uncertainty or incapacity to keep the hand in a fixed position in relation to the forearm
- specific functions (see page 00) and dominance (i.e. which hand was used preferentially for particular activities. This is usually, although not necessarily, the dominant hand)
- other complaints (malaise, fatigue, etc.)
- the patient's ultimate subjective evaluation.

As regards *pain*: 25 patients (still) complained of pain (37.9%)
Reduced strength was reported by 9 patients (13.6%)
Lack of grip strength was mentioned by 23 patients (34.8%) and
instability was part of the anamnesis in 11 cases (16.7%).

Specific functions and dominance

The patients were also questioned concerning possible difficulties in performing activities of daily life (A.D.L.), viz. writing, phoning, dressing/undressing, tying knots or bows, use of cutlery, pouring out, use of screwtops/caps, can and bottle opener, corkscrew, driving a car, riding a moped or bicycle, handling money, and using a hammer, 12 activities in all.

They were also asked which hand they preferred to use for these activities. This was not necessarily the dominant hand, but as a rule it was.

* Performed in cooperation with Miss P. Vleugel, ergotherapist.

At the follow-up examination, 46 patients reported a change of preference of the hand used for one or several activities.

Other complaints

Grouped under this heading were those sensations which, although clearly recognizable to the patient, were often somewhat difficult to define, such as sensations of fatigue, local malaise, the sensation that the hand or wrist felt different from the non-operated side, etc.

Subjectively, these were found present in a large proportion, as listed below:

none	31 (47.0%)
in the hand	9 (13.6%)
in the wrist	14 (21.2%)
in the hand and wrist	12 (18.2%)
total	66 (100 %)

Summing up, these sensations existed in 35 of the 66 cases (53%).

The subjective final evaluation (= own opinion) of the patient

For this purpose, the patient was asked to choose from the following possibilities: improved, no change and deteriorated. This led to the following subdevision:

improved	53
no change	6
deteriorated	7
total	66

To sum up, symptoms were attenuated in 53 cases (80.3%), unchanged in 9.1% and aggravated in 10.6%.

V.2. The orthopaedic examination of the local and regional states

This examination consisted of:

A. inspection and palpation of the limb in question
B. measuring, with a goniometer (as described by the American Academy of Orthopedic Surgeons in Joint Motion, 1965) of the ranges of active and passive motion in the joints in question (wrist, hand and fingers and shoulder and elbow, respectively).
C. Determination of motor activity (muscle strength), sensibility and reflexes (using the muscle strength scale of the American and British Academies of Orthopedic Surgeons) (A.M.A., 1971):

5 – normal	: full range of motion against gravity and maximal resistance
4 – good	: full range of motion against gravity and slight resistance
3 – fair	: full range of motion against gravity
2 – slight	: full range of motion in absence of gravity
1 – trace	: slight muscular contraction – no articular motion
0 – nil	: no trace of muscular contraction

A comparative examination was made of the operated and of the non-operated side.

V.2.1. Local state

Sub A. Inspection and palpation

The *inspection* concerned the appearance of the scar, the position of the arthrodesis, differences in circumference and atrophies.
In regard to the *scar*. In 52 wrists, the scar was unobtrusive or almost invisible, i.e. it appeared as a very thin line, not noticed at first glance. In 14 cases, on the other hand, the scar was wide and clearly visible.
In assessing the *position of the arthrodesis*, we determined whether the hand was in an unnatural position in relation to the forearm (6 cases), whether the stiffening of the wrist was clearly visible (24 cases) or whether the position of the hand in relation to the forearm looked natural, so that the stiffening of the wrist joint was not noticeable at first glance (36 cases).
Difference in circumference and/or atrophy was quantified; the circumference of 53 of the 66 wrists was found to equal that of the other wrist or to differ by 1 cm in a positive or negative sense. In 8 cases there was a 2 cm difference to the disadvantage of the operated wrist and in 5 cases, a 4 cm difference. These 13 patients all belonged to group IV.

At *palpation* of the arthrodesis area, pain was reported by 25 patients, variously provoked by local pressure, axial pressure or a jerking movement. No other palpatory abnormalities were recorded.

Sub B. Local mobility in the wrist joint

This established whether from the *clinical* point of view the arthrodesis had been successful which implied that the wrist joint was immobile = ankylotic. To determine this, the examiner looked not only for any possibility of active motion in the wrist joint but also for passive mobility, by exerting force on the wrist joint in several directions. If mobility was observed, which was often associated with pain, the condition was classified as a pseudarthrosis.

Of the 66 operated wrist joints, 58 at follow up were classified clinically as ankylotic. (This figure includes - see page 47 - the consolidated and the fibrous-ankylotic wrist joints, since these could only be distinguished radiologically.) The remaining 8 showed clear mobility and therefore were pseudarthrotic. These 8 patients were distributed over the indication groups as follows:
Group I: 4; Group II: 1; Group III: 1; Group IV: 2.
(The relationship of these figures to the values found at removal of the cast - see page 47 - will be considered in the discussion of the results on page 97 and following.)

Goniometry of the position of the arthrodesis

Goniometry permitted determination not only of any mobility in the wrist joint but also of the position of the hand in relation to the forearm. This was recorded in two directions: dorsopalmar and radioulnar.

In order to enable an evaluation of these 'wrist positions', we devised a classification based on the J.A.M.A. ankylosis table. For this purpose, the dorsopalmar flexion position and the radio-ulnar abduction position were regarded as equally important. As reference values (best = low-scoring value), we adopted those positions that in the literature are mostly referred to as the 'optimum position of function': 10 to 25° dorsiflexion and 10 to 20° ulnar abduction.
From this starting point, abnormal positions were scored on the J.A.M.A. ankylosis scale, which yielded the following distribution:

dorsiflexion		**ulnar abduction**	
+35° or more:	4	+25° or more:	4
+25 to +35°:	3	+20 to +25°:	2
+10 to +25°:	1	+10 to +20°	1
0 to +10°:	2	0 to +10°:	2
−10 to 0°:	3	−10 to 0°:	3
−10° or less:	4	−10° or less:	4

The sum of the values allotted to dorsiflexion and ulnar abduction is the actual score of the wrist position or 'wrist score'. This score indicates the results as follows:

2 = very good
3 = good
4 = fair
5 = bad
6 = very bad
7 = extremely bad.

In this connection it should be kept in mind that the positions corresponding to scores 2, 3 of 4 are all within the limits given in the literature of the 'position of function' (See Table 1, pages 18, 19).
The wrist scores ranged from 2 to 7 inclusive and subdivision by indication group yielded the following distribution:

TABLE 8

wrist score	*2*	*3*	*4*	*5*	*6*	*7*	*total*
Group I	1	6	1	–	–	–	8
Group II	2	8	6	1	–	–	17
Group III	–	10	6	1	–	–	17
Group IV	3	5	3	3	1	1	16
Total	6	29	16	5	1	1	58
	10,3%	50%	27.6%	8,6%	1,7%	1,7%	100%

This shows that of the patients evaluated, 50% had a good and 10.3% a very good wrist score.

Sub C. Motor activity, sensibility and reflexes

Just as the preoperative examination (see pages 37-39), the follow-up examination also included determination of the mobility of hand and fingers (flexion/extension, opposition/reposition, spreading, adduction):

TABLE 9

	group I	*group II*	*group III*	*group IV*	*total*
normal	11	17	13	2	43
reduced	1	1	5	14	21
impossible	–	–	–	2	2

The mean strength of the hand muscles, measured as described on page 52), was also recorded. In this regard it should be remembered that the pain factor could not be eliminated.

TABLE 10

*Strength score**	*group I*	*group II*	*group III*	*group IV*	*total*
5	7	15	9	2	33
4	4	3	6	3	16
3	1	–	2	1	4
2	–	–	–	–	–
1	–	–	1	3	4
0	–	–	–	9	9

* as defined on page 52

When the coarse classification used at preoperative registration - normal, partially impaired/reduced and none - is applied here, also, and strength values 5 and 4 are classified as normal, values 3 and 2 as partially impaired/reduced and values 1 and 0 as none, the following distribution is found:

TABLE 11

Hand muscle strength

	group I	*group II*	*group III*	*group IV*	*total*
normal	11	18	15	5	49
partially impaired or reduced	1	–	2	1	4
none	–	–	1	12	13

If from among the total of manual muscle functions only grip force was considered, the following result was obtained:

TABLE 12

Grip force

	group I	*group II*	*group III*	*group IV*	*total*
normal*	5	12	9	4	30
reduced	7	6	8	11	32
none	–	–	1	3	4

*i.e. at least equal to the other side.

Of the 8 patients with pseudarthroses, one was found to have normal grip strength and 7, reduced grip strength.

As regards *sensibility*, we observed one case of hypaesthesia and two of hyperaesthesia of the dorsum of the hand (in one of the latter patients, this area had been hypaesthetic before the operation).

V.2.2. Regional state

Sub A. Inspection

Differences in circumference of upper arm and forearm are listed in the table below in which the values measured on the non-operated side are deduced from those found on the operated side.

This circumference was measured at 15 cm proximally and 10 cm distally of the tip of the olecranon, with the elbow in 90° flexion.

TABLE 13

Circumference compared with non-operated arm

Upper arm			Forearm		
−10 cm	: 3		−10 cm	: 4	
−10 to −5 cm	: 4		−10 to −5 cm	: 9	
− 4 cm	: 3		− 4 cm	: 5	
− 3 cm	: 6		− 3 cm	: 4	
− 2 cm	: 11		− 2 cm	: 12	
− 1 cm	: 18		− 1 cm	: 12	
− 0 cm	: 15	50 (75.8%)	− 0 cm	: 15	42 (63.6%)
+ 1 cm	: 4		+ 1 cm	: 2	
+ 2 cm	: 2		+ 2 cm	: 1	
			+ 3 cm	: 2	

If we regard as normal a difference in circumference of plus or minus 2 cm, we find that where the upper arm is concerned, 50 cases (76%) fell into this category; where the forearm was concerned, this number was 42 (64%). The major differences were observed in patients from the neurological group, and especially in those in whom due to congenital disorders, growth and development of the extremity had also been impaired.

Palpation revealed no findings of significance.

Sub B. Mobility

The examination included determination and comparison of the function and mobility of the forearm, the elbow and the shoulder. Mobility functions of the forearm (pronation-supination), elbow and shoulder joints were recorded in the same way as preoperatively (see Table 4, pages 37-39).

TABLE 14

Function and mobility of the forearm, the elbow and the shoulder

	group I	*group II*	*group III*	*group IV*	*total*
Impairment of pronation-supination:					
none (0%)	10	17	6	2	35
slight (1-30%)	2	–	6	3	11
moderate (31-60%)	–	1	5	3	9
severe (61-90%)	–	–	–	4	4
a-functional (91-100%)	–	–	1	6	7

TABLE 14 (cont.)

	group I	group II	group III	group IV	total
Impairment of elbow function					
none (0%)	12	18	15	5	49
slight (1-30%)	–	–	1	6	7
moderate (31-60%)	–	–	2	–	2
severe (61-90%)	–	–	–	3	3
a-functional (91-100%)	–	–	–	4	4
Impairment of shoulder function					
none (0%)	12	18	17	6	53
slight (1-30%)	–	–	1	4	5
moderate (31-60%)	–	–	–	–	0
severe (61-90%)	–	–	–	5	5
a-functional (91-100%)	–	–	–	3	3

Sub C. Motor activity, sensibility and reflexes

For purposes of classification of the strength of the elbow and shoulder musculature, we applied the same rough system as at preoperative registration:

TABLE 15

Muscles serving elbow and shoulder joint

	group I	group II	group III	group IV	total
Elbow musculature					
normal	12	17	16	8	56
partially impaired or reduced	–	1	2	6	9
a-functional	–	–	–	4	4
Shoulder musculature					
normal	12	18	15	9	54
partially impaired or reduced	–	–	3	7	10
a-functional	–	–	–	2	2

As regards sensibility, we once found hypaesthesia of the upper arm and once, hypaesthesia of the forearm. Both had been present prior to operation. No differences in reflexes compared with the preoperative condition could be established.

V.2.3. Local and regional states of the donor site

The 61 donor sites were also examined.

Sub A. Inspection and palpation

In judging the scar, the same criteria were applied as in the carpal region. There were 48 cases of very good wound healing. In one case, the scar was irregular and markedly widened, and in 12 cases, the scar was clearly visible but not obtrusive.

Palpation and pressure still caused pain or sensations of discomfort at the donor site in 11 cases (7 ilia and 4 tibias).

Reduced sensibility around the donor site was encountered 6 times, distributed equally over ilia and tibias.

Atrophies of the donor lower leg amounting to more than 2 cm compared with the non-operated side, were not seen, nor were any disorders of knee or ankle function observed.

V.3. Radiological evaluation

X-ray examination was performed to determine:

1. whether bony continuity had developed in the arthrodesis tract
2. whether there were interruptions of this bony continuity, and if so at what levels
3. the extent of the arthrodesis (carpal fusion, taking of the graft)
4. the position of the arthrodesis (angle of distal radius and metacarpus).

The X-rays made at follow-up were measured and compared. They were made in two projections: anteroposterior and lateral.

The angles measured were: (Fig. 17)

1. the angle between the radius and the IInd metacarpal,
2. the angle between the radius and the IIIrd metacarpal, both measured in the anteroposterior X-ray film, and
3. the angle of dorsiflexion, or the angle between the radius and the IIIrd metacarpal, measured in the lateral projection.

Owing to imperfect projection, the values found were not always absolutely correct, so that the following should not be interpreted in any absolute sense, but rather be regarded as an indication.

Still, subsequent comparison of the X-ray measurements with the wrist position measured externally never revealed differences exceeding 5°.

Sub 1. Bony continuity

At the follow-up X-ray, of the 66 wrists 15 were found to lack bony continuity (classified by indication groups: Group I: 7; Group II: 4; Group III: 3 and Group IV: 1).

Sub 2. Level of the interruption in the bony continuity

Bony continuity was lacking in 15 arthrodesis tracts, classified by anatomical joint levels as follows:

at radiocarpal level	1
at carpal level	1
at carpometacarpal level	12
at several levels (due to graft absorption)	1

Fig. 17. Determination of the posture of the hand in relation to the forearm in the wrist joint by measuring of the following angles:

A: angle in anteroposterior projection between

B: lateral projection:
4. angle between radius and IIIrd metacarpal bone = dorsiflexion angle

1. radius and IInd metacarpal bone = radius – MC II angle
2. radius and IIIrd metacarpal bone = radius – MC III angle

(patient operated according Butler's technique – iliac graft)

Sub 3. Extent of the arthrodesis: Graft fusion and carpal fusion

At follow-up, 19 of the 62 bone grafts used were still clearly visible (18 tibial and 1 iliac graft). Mostly, these grafts could be distinguished from the surrounding bone structures because they showed a sclerotic appearance. Another aspect considered was the socalled carpal fusion, the bony union of the carpal bones. For this purpose, Navarro's (1937) grouping of the carpal bones proved very useful (see page 5). Navarro divided the carpal bones into three vertical columns with as column 1, the radial carpal bones: scaphoid, trapezoid and actually, the trapezium as well (but as mentioned before, this was excluded from the ankylosis in all cases). The second, central column consists of the lunate, capitate and hamate bones and the third, ulnar column consists of the triquetral bone (see Fig. 18).

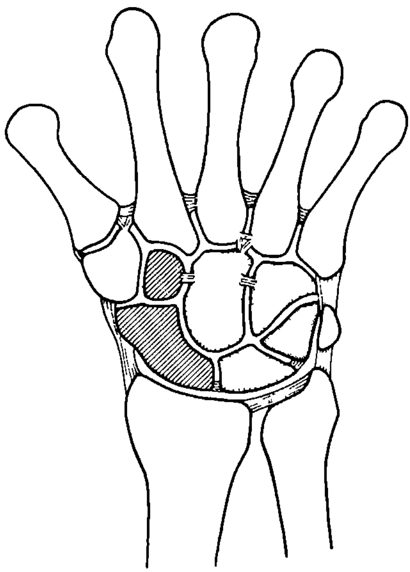


Fig. 18. The carpal columns according to Navarro (1939)

= column 1

= column 2

= column 3

We classified the degree of bony union as: none, partial or complete. We applied the criterion that when the articular cleft or the freshened articular cleft remnants were still clearly visible, there was *no* union; when these clefts were no longer visible, there was *complete* union and when they were still partly visible, there was *partial* union.
Distribution of these fusions over the various carpal columns gave the following results:

TABLE 16

Carpal fusion

	column 1	*column 2*	*column 3*
none	4	2	30
partial	48	10	9
total	14	54	27

Sub 4. The position of the arthrodesis

By measuring, the position of the arthrodesis could be determined in two directions. The average angle of the arthrodesis at follow-up in all radiologically consolidated wrists (51) was:

- dorsiflexion: 13.40°
- angle between radius and MC II: −1.83° (− is open toward the radius)
- angle between radius and MC III: +9.19° (+ is open toward the ulna).

V.4. Ergonomic evaluation

Since wrist arthrodesis affects the function of the extremity as a whole, it also influences the private and occupational working capacities of the patient.

Ergonomics being 'the science of adjusting the work situation to man's nature and limitations', it appeared useful to include the ergonomic aspects of a wrist arthrodesis in the investigation.

In addition, this might reveal possible impairment that might be improved by ergotherapy. (Ergotherapy = systematical exercises to restore functions weakened or abolished by disease or other factors. It is not limited to occupational activities but also includes activities of daily life: A.D.L. training.)

Accordingly, where occupational activities and A.D.L. are concerned, an ergonomic examination is more complete than an orthopaedic-functional examination. Attention is given to the following aspects:

- occupational and other activities
- handedness (main hand-secondary hand)
- dominance
- stereognosis
- functional value
- incorporation into the body scheme.

These concepts will be explained below.

V.4.1. Material and method

I. Material

Since ergonomic evaluation involves comparison with the healthy (normal, non-operated) side, it can be carried out only in patients with unilateral pathology.

This excluded from analysis four patients with 5 wrists, all in group III, leaving 61.

Classified according to clinical and radiological criteria, there were

- 7 patients with a *pseudarthrosis*
- 10 patients with a *fibrous ankylosis*
- 44 patients whose arthrodeses were *consolidated.*

II. Method: 'The block scores'

The 61 patients were subjected by an ergotherapist to a number of examinations and tests. The tests were grouped into four socalled 'blocks'. In composing the blocks, use was made of data and tests from the literature: Slocum (1946); Bechtol (1954); Moberg (1958); Swanson (1964, 1973); Carroll (1965); Clawson (1971); Kraft (1972); Malick (1972); Prollius (1973); Corstens (1976).

The blocks included the following functional records:

block 1: hand and finger function
block 2: various grips, strength of extension and grip
block 3: test programme for the function of the upper limb
block 4: bimanual specific functions.

Per block, after conversion, for all elements combined a maximum of 100 points can be scored per extremity. Consequently, the difference between the scores of the non-operated healthy side and the operated side may range from 0 to 100 points.

The ultimate result is scored as follows:

$\leqslant$ 0 points = 1 = very good
1- 30 points = 2 = good
31- 60 points = 3 = fair
61- 90 points = 4 = bad
91-100 points = 5 = very bad

Description of the blocks

Block 1: This consists of a dozen different hand and finger functions. Since from the ergonomic-ergotherapeutic viewpoint these functions are not all of equal importance, they are multiplied by an ergonomic evaluation factor as shown below.

TABLE 17

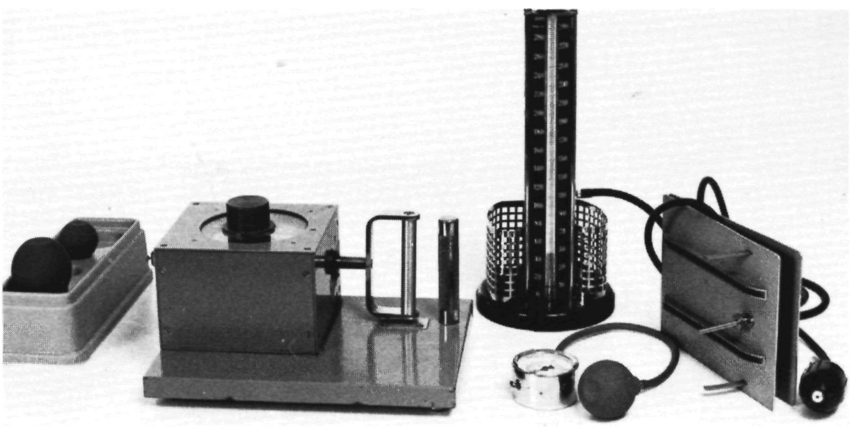
hand and finger function	ergonomic evaluation factor
finger flexion	3
finger extension	2
adduction thumb	2
abduction thumb	3
opposition thumb	4
reposition thumb	2
finger-spreading	1
finger-closing	1
isolated movements	2
lateral grip	3
pronation	1
supination	1

The findings are scored as follows:
normal = 0
slow or clumsy = 1
partial performance possible, with compensation if necessary = 2
impossible = 3
Accordingly, the best possible score for all functions combined (i.e. the sum of the scores multiplied by the corresponding evaluation factor) is zero, the worst possible score is 75 points. In order to enable comparison by percentages, the scores obtained on the operated as well as on the non-operated side are multiplied by 100/75. The difference between these values found for the normal and the operated side is *block score 1*.

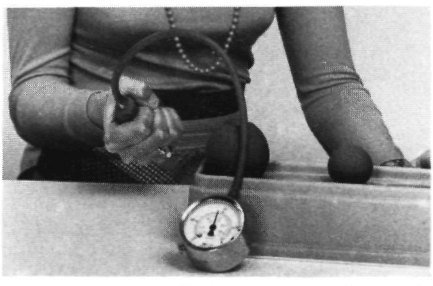
Block 2: consists of the following measurements: (Fig. 19)

1. measurement by means of the vigorimeter of
   a. the ball grip → whole hand grip
   b. the cylinder grip → whole hand grip
   c. the thumb-finger pinch grip

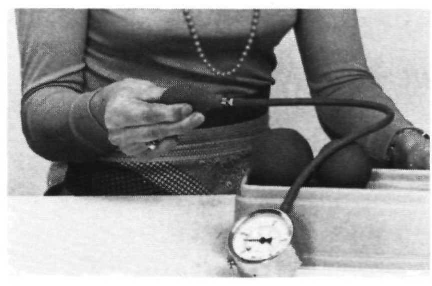
Fig. 19. Ergonomic test block 2.



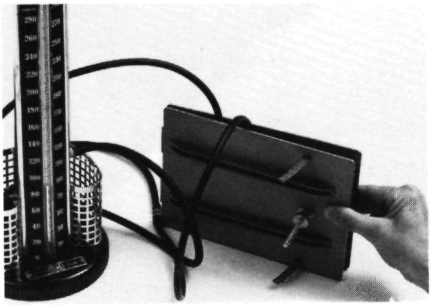
A. Recording equipment left to right, balloons for vigorimeter, dynamometer, vigorimeter (foreground), mercury manometer



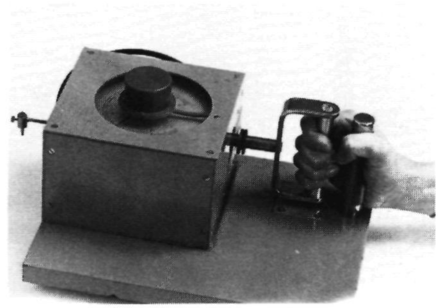
B. measuring whole hand grip with vigorimeter



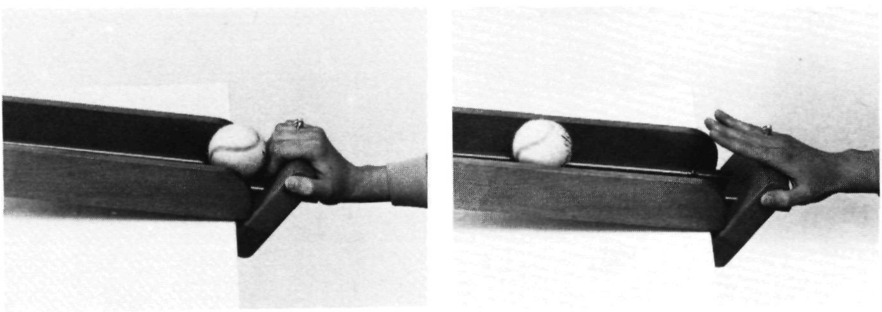
C. measuring pulp grip with vigorimeter



D. measuring pulp grip with mercury manometer



E. measuring grip force (whole hand grip) with dynamometer



F. measuring extension force with digital extension equipment

2. measurements of the pinch grip by means of a specially designed mercury manometer.
3. measurement of the grip force by the means of the dynamometer.
4. measurement of the extension force by means of the digital extension apparatus.

Each determination can yield a maximum of 10 points.
Subsequently, all factors obtained are multiplied by an ergotherapeutic evaluation factor.
This factor amounts to 2 for the ball grip, cylinder grip and pinch grip and to 1 for the digital extension measurement and the grip force measurement so that the maximal (best) score per extremity is 100 points.
The difference between the total number of points on the non-operated side and that on the operated side constitutes *block score 2*.

Block 3: This consists of the values obtained by the modified and supplemented version of the UEF test (Upper Extremity Function Test of Douglas Carroll M.D. from The Journal of Chronic Disease, 1965).

Using the affected hand, the patient had to manipulate a test platform and manipulate or lift the following objects (15 activities in all, Fig. 20):

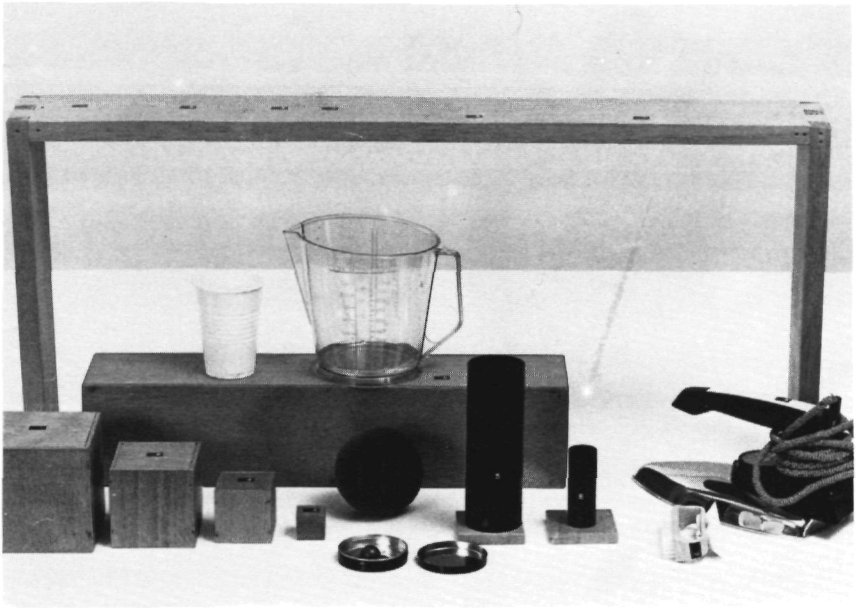


Fig. 20. Set-up for ergonomic test block 3 (see Table 18)

TABLE 18

- 4 blocks (measuring 10, 7.5, 5 and 2.5 cm in diameter)
- 2 cylinders (5 and 2.5 cm in diameter)
- ball
- 4 beads (2, 1.5, 1 and 0.5 cm in diameter)
- paper-clip
- safety pin
- nail
- nailbrush
- flat-iron
- pouring from a can in pronation
- pouring from a can in supination
- writing
- handling coins
- lighting a match and waving it out
- handling cigarette lighter.

Here, also, the score run from normal = 0 to impossible = 3. The total score, therefore, may range from 0 to 45 points. Once more, to obtain values on a scale from 0 to 100, the total score for each extremity is multiplied by 100/45. The difference between the values obtained in this manner for the operated and the non-operated side constitutes *block score 3.*

Block 4: This block consists of twenty specific functions to be performed bimanually (Fig. 21):

Fig. 21. Ergonomic test, block 4. Specific manual functions (see Table 19)

TABLE 19

- tearing a newspaper	- carpentry
- cutting paper with scissors	- screwing/unscrewing jam jar lid
- cutting cardboard with scissors	- screwing/unscrewing bottle cap
- slicing gingerbread	- fastening/unfastening 6 nuts and bolts
- uncapping bottle	- winding watch
- undoing 6 buttons	- opening purse
- fastening 6 buttons	- handling safety pin
- undoing 6 bows	- handling paper-clip
- tying 6 bows	- threading a needle
- phoning	
- stringing beads (3 of 2 cm, 3 of 1.5 cm and 3 of 1 cm in diameter).	

It was noted whether the operated side indeed performed its natural function in these actions (i.e. whether the dominant hand is used as such, whether the non-dominant assisted, and to what degree). Here again, the scores ranged from normal (= 0) to impossible (= 3), so that the total score ranged from 0 to 60, to be adjusted to a percentual scale by multiplying by 100/60. The value thus calculated for the operated side constitutes *block score 4*.

V.4.2. Block score results

In 61 patients the test results for all four blocks could be determined and these were grouped per block and per indication group (see Tables in Appendix II, IIA, IIB).

The findings show that patients of groups I and II mostly score high to very high on all blocks, whereas patients of group III had scores with more variability, from very good to fair.

Patients of group IV scored mostly fair and low, with only a few good and very bad scores.

Within the indication groups there was a demonstrable correlation between the various block scores.

The tables show that patients with pseudarthrosis or a fibrous ankylosis did not present a score pattern different from that of those with a consolidated arthrodesis.

The question was studied whether there was a correlation between the various block scores per group and the individual wrist scores.

From the findings obtained, no such correlation could be deduced.

Possible influence on the block scores was determined of the following factors:

TABLE 20

Factors influencing the block scores

Effect demonstrable	*yes*	*no*
dominant/non-dominant hand		×
surgical technique		×
graft type		×
sex		×*
length of time since onset		×
preoperative function	×**	
consolidation time		×
stereognosis		×
physical therapy		×
ergotherapy	too few cases	
current work	too few cases	
preoperative stress on wrist		×
postoperative stress on wrist		×

* women appear to do slightly better

** patients with bad block scores had already had bad carpal function prior to operation while the converse proved not to be the case. In other words, there were patients with bad preoperative function who nevertheless received good scores!

TABLE 21

Preference shift pattern

	preference not shifted	*preference shifted*	*irrelevant**
writing	42 (63.6%)	10 (15.2%)	14 (21.2%)
phoning (dial)	53 (80.3%)	11 (16.7%)	2 (3.0%)
dressing/undressing	60 (90.9%)	5 (7.6%)	1 (1.5%)
tying knots/bows	56 (84.9%)	9 (13.6%)	1 (1.5%)
using cutlery	48 (72.7%)	17 (25.8%)	1 (1.5%)
pouring	45 (68.2%)	17 (25.8%)	4 (6.1%)
screw-tops/caps (turning hand!)	32 (48.5%)	30 (45.4%)	4 (6.1%)
opening cans/bottles	35 (53.0%)	15 (22.7%)	16 (24.3%)
corkscrew	32 (48.5%)	15 (22.7%)	19 (28.8%)
car/moped/bike	55 (83.3%)	6 (9.1%)	5 (7.6%)
handling money	49 (74.3%)	14 (21.2%)	3 (4.5%)
hammering	45 (68.2%)	13 (19.7%)	8 (12.1%)

* was not done with the hand in question or patient had it done by someone else.

When we regard the shift situation per activity, in other words when we calculate the shift proportion only for those cases in which a shift might have occurred, the following data emerge:

TABLE 22

screwtops	30 out of 62 :	48.4%
corkscrew	15 out of 47 :	31.9%
can-/bottle opener	15 out of 50 :	30.0%
pouring	17 out of 62 :	27.4%
handling cutlery	17 out of 65 :	26.2%
hammering	13 out of 58 :	22.4%
handling money	14 out of 63 :	19.2%
writing	10 out of 52 :	19.2%
phoning	11 out of 64 :	17.2%
tying knots/bows	9 out of 65 :	13.8%
car/moped/bike	6 out of 61 :	9.8%
dressing/undressing	5 out of 65 :	7.7%

This shows that the proportion of shifts is clearly larger for those activities that require a power grip than for activities that require precision handling.

V.4.3. Functional value and compatibility with the body scheme

The ergotherapist determined not only the degree of impairment of the kinetic functions of the affected limb (functional value) but also whether the limb was included into the normal kinetic automatism (= compatible with the body scheme) or excluded from it (e.g. lazy eye). The possibility exists, namely, that a patient with an impaired extremity adequately performs a required test but does not use the extremity in everyday activities.

This has important implications for A.D.L. as well as for capacity to work. Ergonomists as a rule regard compatibility with the body scheme as more important than functionality, because in their view, an inadequately functioning limb that is being used (i.e. fitted into the body scheme) constitutes a better result than an extremity which, although adequately functional, is not being used (not fitted into the body scheme).

Thus, four categories can be distinguished:

1. *good* functional value *with* compatibility with the body scheme
2. *good* functional value but *no* compatibility with the body scheme
3. *inadequate* functional value *with* compatibility with the body scheme
4. *inadequate* functional value and *no* compatibility with the body scheme.

Of these categories, 1 is regarded as the best and 4 as the worst.

Accordingly, the patients were grouped into the above categories on the basis of the overall judgement of the ergotherapist.

For the total number of patients this gave the following subdivision:

TABLE 23

Functionality + compatibility with body scheme

	functionally adequate + compatible	*functionally adequate + not compatible*	*functionally inadequate + compatible*	*funtionally inadequate + not compatible*	*total*
group I	6	4	1	1	12
group II	13	3	1	1	18
group III	9	3	3	3	18
group IV	2	1	6	9	18
	30	11	11	14	66

Our personal clinical material failed to confirm the above ergotherapeutic viewpoint: the number of patients with an adequately functional extremity (41) precisely equalled the number of patients in whom the arm and hand

were compatible with the body scheme.
The possible influence was also studied of such factors as dominant/non-dominant hand, sex, presence or absence of pseudarthrosis, capacity to work, handicap and preoperative carpal function. No such influence could be demonstrated. The same applied to the wrist position score.

V.4.4. Stereognosis

The patients were also subjected to a stereognosis test:
Recognition by touch, of shape, surface and consistence of offered objects. Using their operated limb, the patients had to distinguish the following ten objects (Fig. 22):

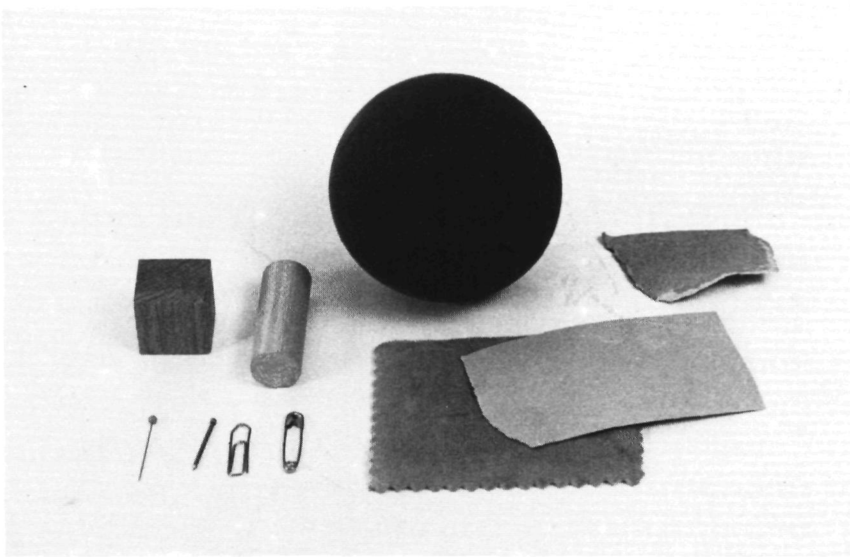


Fig. 22. Test objects used for examination of stereognosis

TABLE 24

- a cube	- a pin
- a cylinder	- a safety pin
- a ball	- a piece of felt
- a paper-clip	- a piece of emery paper
- a nail	- a piece of paper.

Eight patients had impaired stereognosis.
Subdivision by group:
Group I: 1
Group II: 0
Group III: 1
Group IV: 6 (= 33.3%!), of whom one had a pseudarthrosis.

Of these 8 patients, 7 had a functionally inadequate limb not compatible with the body scheme while one (neurological) patient had a hand that was functionally inadequate but was compatible. Evidently, impaired stereognosis adversely affected both functional value and compatibility. Handedness was found not to affect the stereognosis.

CHAPTER VI. ASPECTS PERTAINING TO OCCUPATION AND CAPACITY TO WORK

VI.1. Introduction

Because, as confirmed by the ergonomic evaluation, an arthrodesis of the wrist joint affects the use of the hand and arm, it is to be expected that it will cause problems in certain occupations. We should therefore attempt to gain some insight into this aspect. In addition, if the primary pathology causes occupational problems exclusively, it is advisable to consider whether the occupation might be resumed after wrist arthrodesis. Where this possibility does not exist, the indication for the intervention would become questionable, and the patient might be spared an operation.

The degree of (in)capacity to work after adjustment and adaptation of the patient depends on the demands the occupation makes on the wrist. Naturally, this involves not only the possibilities of moving the wrist joint but also the strains exerted on this joint during the work, which is why labour experts distinguish *wrist motion* and *wrist strain*.

In consultation with labour experts of G.A.K. (Joint Administration Office, administering obligatory sickness insurance) and medical officers of G.M.D. (Municipal Medical Service), an attempt was made to gain some insight into the degrees of *heaviness* of our patients' jobs.
(N.B. The Dutch labour criteria were applied.)

In this chapter, we shall successively review incapacity to work and current occupation, and make an analysis with a view to the occupation with direct comparison of preoperative findings and findings at follow-up.

VI.2. (In)capacity to work

All patients were questioned regarding their pre- and their postoperative fitness to work; the results of this questioning are shown in Table 25.

TABLE 25

group	100% fit. for work		50%		0%		potentially 100% unfit for work*		unfit for work for some other reason	total
I	–	**1**	1	**3**	11	**6**	–	**–**	**2**	12
II	–	**7**	5	**7**	3	**4**	–	**–**	**–**	18
III	1	**6**	9	**5**	8	**6**	–	**–**	**1**	18
IV	–	**7**	3	**4**	8	**3**	7	**3**	**1**	18
	1	**21**	18	**19**	40	**19**	7	**3**	**4**	66

Roman = pre-operative
Bold = postoperative

* Regarded as potentially unfit for work were those neurological patients who already had made a job selection determined by their handicap. They had found jobs which required little or no use of the wrist so that they were fit to work in their own occupation but would have to be regarded as unfit for any other occupation that would require some degree of wrist function.

This shows that the increase of patiënts 100% fit for work occurred mostly in groups II, III ans IV.

VI.3. Current occupation

Patients were asked about their current occupations and on the basis of their answers, could be classified as follows:

A. patient engaged in the same occupation as before operation
B. patient unemployed *irrespective* of his carpal pathology
C. patient engaged in different but equally heavy work, *irrespective* of the pathology
D. patient engaged in different, lighter work, *irrespective* of the pathology
E. patient engaged in lighter work *because* of the pathology
F. patient no longer working *because* of the pathology.

TABLE 26

group	*A* *as pre-operative*	*B* *not working regardless of disorder*	*C* *other equally heavy work*	*D* *lighter work regardless of disorder*	*E* *lighter work because of disorder*	*F* *not working because of disorder*	*total*
I	–	1	2	–	3	6	12
II	5	–	–	2	7	4	18
III	2	4	2	–	4	6	18
IV	4	–	7	1	4	2	18
	11	5	11	3	18	18	66

The above table shows that in:

- group I: due to their lesions, 6 out of 12 patients were no longer working, and 3 had to fall back on lighter work;
- group II: 5 patients returned to their former jobs, while because of their lesion, 7 patients had to do lighter work and 4 were no longer working;
- group III: one-third (6 patients) were no longer working because of the wrist affection, 4 patients had had to fall back on ligher work and only 2 had resumed their former occupation;
- group IV: 4 patients were no longer working, 2 did lighter work and almost two-thirds of this group could do the same or equally heavy work.

In this connection it should be remembered that these patients to some extent represented a selection because most of them had suffered from their abnormality from birth.

When we consider the 36 patients who because of their disorder had to do lighter work or were unfit to work (in Table 26, categories E and F), we find that this group includes 7 of the 8 patients with a pseudarthrosis and 7 of the 10 with a fibrous ankylosis. Of the 22 others, 18 proved to be affected on their side of preferential use. All these 22 before operation had had jobs involving heavy work, such as: hodman, building labourer, mechanic or butcher. Of the 11 patients able to resume their preoperative occupations (in Table 26, category A), 7 had been operated on their side of preferential use. Of these 11, only 3 did heavy work (mechanic, bricklayer, roadworker).
Four patients mostly had difficulties while performing their occupational work. Postoperatively, one patient could resume his preoperative work (milkman, group II), one, (a leather worker, group I) had to fall back on lighter work and two (a female packer and a storeroom clerk, group III) were judged unfit for work. All four had been operated on their side of preferential use.

VI.4. Analysis pertaining to the occupation

Job analysts of G.A.K. and G.M.D. categorized the occupations of our patients with regard to the requirements made by those occupations on the wrist joint. They had to work with function *designation* because function *analysis* was no longer possible. Conditions to be met by a wrist joint fall into two groups, related to the degree of wrist strain and to movements of the wrist joint involved in the work.

All occupations involving physical effort have been classified according to the effort required by the former National Labour Office (currently, General Directorate of Labour) in a publication entitled 'Classificatie van beroepen naar hun onderlinge verwantschap' (Classification of occupations by degree of similarity) (R.A.B., 1952):

Category A: groups of occupations involving very light work, to category C: groups involving very heavy work, and category B: occupations involving work of an intermediate degree of heaviness.

VI.4.1. The degree of wrist strain

Occupational labour involves the exertion of forces required for pushing, lifting, wringing, levering, turning, pinching, grasping and swinging. Factors that may determine the degree of wrist strain are:

1. the intensity of the forces to be exerted;
2. the frequency and duration of the forces to be exerted, per activity or performance of a normal work day;
3. the nature of the strain (static, dynamic or mixed);
4. the position of the wrist at the time the forces have to be exerted.

Starting from these assumptions, ergonomists and labour analysts have drawn up a general, approximative classification, based on designation of functions:

1. *no* strain of significance
2. *mild* strain
3. strain neither mild nor heavy = *intermediate*
4. strain definitely *heavy*.

VI.4.2. Demands on wrist motion

These have two aspects:

1. the carpal movements to be made, dorsal/palmar flexion, radial and ulnar movements
2. the position of the wrist during the work

   Examples: a garage mechanic working on the fascia board, a waiter carrying a tray above his head with the hand overextended in maximal dorsiflexion of the wrist.

Demands on wrist movements were classified as follows:

1. none	3. moderate
2. slight	4. heavy.

The ergonomists remark in this connection: since the figures 1-4 represent only a sequence but not a quantification, no addition or multiplication is permissible, not even per category (strain, movement).
Ability evaluation is only possible on the basis of the place of the occupation in the sequence, determined by the wrist strain and wrist motions involved. Where a choice has to be made between preservation of strength and preservation of mobility, the place of the job in the sequence may provide some guidance.
Furthermore, it is to be expected that loss of performance will occur soonest in occupations classified under 3 or 4 as regards both strain and mobility (see Table 26 A).

TABLE 26 A

	degree of wrist strain		*required wrist motion*		*Labour Office code*
Occupation	*dom.*	*non-dom.*	*dom.*	*non-dom.*	
transport worker	4	4	2	2	C
hodman/building labourer	4	4	2	2	C
butcher	4	3	4	2	B
bricklayer	4	3	4	2	B
carpenter	3	2	4	2	B
factory worker	3	3	3	2	(B)
milkman	3	3	2	2	B
concrete worker	4	4	2	2	C
brickmaker*	4	4	2	2	C
road worker	3	3	2	2	C
unskilled worker	4	4	2	2	C
driver**	2	2	2	2	B
paint sprayer	3	1	3	1	B
leather worker	3	3	3	3	B
shoe technician	1	1	1	1	–
mechanical wood worker	3	2	2	1	B
electric welder	3	2	2	1	B
metal press operator	2	2	3	3	C
maintenance mechanic	3	3	4	2	B
diesel mechanic	3	2	4	2	B
car mechanic	3	2	4	2	B
punch operation (protected workshop)	2	2	2	2	B
student-school pupil	1	1	1	1	–
town-planning draughtsman	1	1	1	1	–

TABLE 26 A (cont.)

	degree of wrist strain		*required wrist motion*		*Labour Office code*
Occupation	*dom.*	*non-dom.*	*dom.*	*non-dom.*	
head computer operation office	1	1	1	1	–
production assistant	1	1	1	1	–
packer	2	2	3	3	A
housewife	3	2	3	2	–
permanently invalided out	–	–	–	–	–
greengrocer/chips fryer	3	2	2	2	B
stockroom clerk	3	3	1	1	B
administrative worker	1	1	1	1	–
worker protected workshop	–	–	–	–	–
salesman 'self-service'	2	2	2	1	–
mailman	2	1	2	1	B
pipe bender	4	3	3	1	C
cable layer	3	3	2	1	C
cleaner	3	2	2	1	B
porter	1	1	1	1	B
waiter	2	3	3	2	B

degree of wrist strain		**requirements wrist motion**	
none	1	none	1
slight	2	slight	2
moderate	3	moderate	3
heavy	4	heavy	4

* taking into consideration loading, unloading, turning, sorting by sound and colour.
** Loading and unloading not included in task.

List of occupations of patients subjected to wrist arthrodesis.

VI.5. Evaluation based on job analysis

Per indication group the question was studied whether there were differences in required wrist strain and wrist motion between the occupations performed before, and most recently after the wrist arthrodesis.

A number of patients had been unable to continue in these jobs till the follow-up. With one exception, the lunate bone patients (group II) proved to have had *preoperative* jobs involving *moderate* or *heavy* wrist strain. Where the other indication groups were concerned, this held true of the *wrist motion*, as well.

Forty percent of all patients evaluated had switched postoperatively to jobs

involving less wrist strain or motion. Of the 58 patients with an ankylotic wrist joint (i.e. consolidation and fibrous ankylosis cases together), 4 held jobs involving heavier wrist strain, 29, jobs involving the same degree and 25, jobs involving less wrist strain.
Demands on wrist mobility in the new occupations were heavier in 4 cases, unchanged in 31 and lighter in 23 cases.
The group subdivision is shown in Table 27.

TABLE 27

Comparison of postoperative and preoperative

	group I	*group II*	*group III*	*group IV*	*total*
wrist strain requirements					
heavier	2	–	2	–	4 (7%)
unchanged	2	7	8	12	29 (50%)
less	4	10	7	4	25 (43%)
					58 (100%)
wrist motion requirements					
heavier	1	1	2	–	4 (7%)
unchanged	3	8	8	12	31 (53%)
less	4	8	7	4	23 (40%)
					58 (100%)

The curious fact emerged that 4 patients considered their postoperative work lighter, whereas according to labour experts it was heavier.
No correlation could be demonstrated between the intensity of preoperative wrist motions and strain, and preoperative incapacity to work. No such correlation could be demonstrated postoperatively, either. The consolidation time was not affected by heavier preoperative demands on the wrist.
According to the G.M.D. and G.A.K. labour experts, a wrist arthrodesis does not necessarily reduce working ability, provided the following conditions are fulfilled:

A. a good 'average' position of the wrist
B. no reduction of grip or pinch strength (i.e. complete fist closure possible)
C. no occurrence of pain during use of the hand
D. no reduction of exertion of force
E. no reduction of forearm pronation or supination
F. the possibility during work to compensate for lost wrist motions by motions of the forearm and motions in the elbow and shoulder joints
G. the capacity to shift from dominant to non-dominant hand (for occupational activities and A.D.L.)

H. willingness of the patient to adjust to the situation
J. preparedness of employers to give subjects time on the job to get used and adjust to reduced wrist mobility.

According to labour experts, all the patients in this study should be able to hold their jobs after wrist arthrodesis, provided the above conditions were met (Offringa, 1976).

VII.1. Introduction

In discussing the findings, we have to establish first of all that of the many orthopaedic techniques available for wrist arthrodesis, two have been used in the vast majority of the cases:
- the Brittain-Ely technique (31x) with use of a tibial graft and
- the Butler technique (28x) with use of a graft from the iliac crest.

Also included in the evaluation are 4 wedge resection arthrodeses and 3 radial sliding graft arthrodeses. Surveying the literature (cf. review on page 82 and following), we find that the indications as listed and classified by us (see pages 26 and 34) are still generally accepted, although in recent years, especially for the first three indication groups, alternative methods have been applied, such as partial carpal fusion (literature see page 29), carpal implants of synthetic material, resection arthroplasties and endoprostheses (literature see page 32).

Nowhere in the literature have we been able to find a comparative study of two techniques for arthrodesis of the wrist joint with regard to:
- the subjective result (assessment by the patient) and
- objective evaluation (judgement by orthopaedist and ergotherapist)
  - of the surgical result (aspects regarding to technique, complications and clinical and radiological outcome) and
  - of the functional result (ergonomic evaluation and aspects pertaining to occupation and profession).

The resulting impossibility of a comparison with data in the literature renders it difficult to discuss and assess the results. Data concerning evaluation of results in the literature are listed in the following survey (Table 28).

TABLE 28 LITERATURE SURVEY

RESULTS

Author	*Year*	*Number*	*Indication*	*Technique*	*Complic remarks*	*Evaluation*	*Evaluation criteria*
Ely	1920	2	tuberculosis	tibial graft		consolidated	
Liebolt	1938	44	tuberculosis (23) rheumatoid arthritis (4) birth trauma (1) polio (3) post-traum (2) Volkmann (2) spast (8) not stated (1)	cartilage resection bone chips from radius, carpus, tibia, iliac crest	11 pseudos	23 good 7 fair 10 bad 4 unknown	anatomical appearance symptoms function
Abbot	1942	50	hemispast (16) Volkmann (6) flaccid paresis (20) traum arthrosis (3) tbc (3) congenital lesion (2)	iliac crest chips	1 pseudo		
Brooks	1949	22	peripheral paralysis due to tendon transfers	Smith-Petersen (12) Seddon (4) iliac graft		all consolidated	
Butler	1949	49	post-scaphoid fract arthrosis (21) fract disloc (11) pareses (6) osteochondritis dissecans (1) lunatomalacia (3) rheumatoid arthritis (1) tbc (3) Jungling's disease (1) lunate bone fract (1) infection (1)	iliac graft	2 pseudos	25 very good 14 good 4 fair 6 bad	anatomical appearance symptoms function
Brittain	1952	25	tuberculosis (6) pyoarthritis (7) scaphoid arthrosis (9)	tibial graft	3 pseudos 2 graft fractures	22 consolidated	

TABLE 28 (cont.) *RESULTS*

Author	*Year*	*Number*	*Indication*	*Technique*	*Complic remarks*	*Evaluation*	*Evaluation criteria*
Robinson	1952	12	post-traum arthrosis	prox carp resection fixation capitate bone to radius with screw	none adverse effect on finer manual motoricity	all consolidated	
Wickstrom	1954	25	cerebral palsy (9) congenital paralysis (6) tuberculosis (2) post-traum arthrosis (2) infection arthritis (2) Volkmann (1) rheumatoid arthritis (1) neuroarthropathy (1) polio (1)	Colonna technique costal graft	1 pseudo 1 graft disloc 1 rad abduction	18 out of 21 good	
Evans	1955	19	post-traum arthosis (4) rheumatoid arthritis (1) spast hemiplegia (7) Volkmann (2) arthrogryposis (3) lunatomalacia (1) congenital paralysis (1)	pointed radius into split carpus	postop disloc 2	17 good	subject judgement patient, improved, surgeon unchanged or improved
Merle d'Aubigné	1956	60	traum bone lesions (23) non-traum bone lesions (10) soft-part lesions (18) not followe up (9)	Smith-Peterson (31) variable techniques tibial/ iliac graft	2 graft fractures 7 pseudos 1 dislocation	17 very good 15 good 11 fair 3 bad 5 very bad	see below

very good = no pain during rest or movement, muscle strength good, pronation + supination 90°
good = no pain, muscle strength reduced, pronation + supination 30 to 90°
fair = mild pain on movement not impairing activity, muscle strength reduced, pronation + supination 30 to 90°
bad = pain during rest, muscle strength greatly reduced, pronation + supination less than 30°
very bad = failure of operation

TABLE 28 (cont.)

RESULTS

Author	*Year*	*Number*	*Indication*	*Technique*	*Complic remarks*	*Evaluation*	*Evaluation criteria*
Stein	1958	15	flaccid paralysis (6) spastic paralysis (6) scaphoid pseudarthrosis (1) perilun luxation (1) anklyosis (1)	Gill's			
Cregan	1959	5	rheumatoid arthritis	wedge resection + graft from distal ulna		all consolidated	
McKenzie	1960	34	flaccid paralyses	distal ulna	1 p o median nerve compression	all consolidated	
Hazewinkel	1962	26	scaphoid pseudo lunatomalacia (11) polio (3) post-traum deform (4) spastic hemipl (5) rheumatoid arthritis (1) tuberculosis (1) nerve lesion (1)	modified Brittain + screws	1 tibial fissure 6 graft fractures (sometimes years later!) 1 infection 10 donor leg problems 1 pseudo	3 patients not satisfied, most scaphoid/lun patients lighter work	
Danielsson	1963	17	rheumatoid arthritis (6) post-traum arthrosis (7) lunatomalacia (1) congenital paralysis (1) hemiplegia (1) not followed up (12)	tibial graft	1 wound infection with sequestration 1tibial fracture 3 pseudos due to 3 graft fractures		12 satisfied 3 not satisfied
Hindenach	1963	23	rheumatoid arthritis	distal ulna		all consolidated	
Campbell	1964	8	tumour of radius (2) lunatomalacia (2) pseudarthrosis (1) tuberculosis (1) synovitis (2)	resection of affected carpal bones + iliac bone	2 pseudos without pain	6 consolidated	

TABLE 28 (cont.) *RESULTS*

Author	*Year*	*Number*	*Indication*	*Technique*	*Complic remarks*	*Evaluation*	*Evaluation criteria*
Stjernswärd	1964	43	polio (8) post-traum paralysis (3) spastic paralysis (2) rheumatoid arthritis (9) post-traum arthr (14) lunatomalacia (6)	radial graft 26 tibia 15 ilium 9 ulna 2	strength on operated side always less, 5 (out of 12) patients could resume heavy work 7 had to do lighter work 5 idem irrespective of pathology 10 pseudarthrosis 13x no bony union CMC better 2 postoperative infections	29 no more symptoms 9 marked residual symptoms	
Hussenstein	1964	22	post-traum arthrosis inflammations paralyses	pointed radius in carpus			
Clayton	1965	12	rheumatoid arthritis	iliac graft + intramed fixation	2 pseudos	10 satisfied	
Thomas	1965	16	post-traum arthrosis (9) (due to scaphoid) rheumatoid arthritis (3) lunatomalacia (2) polio (2)	tibial 'bone marrow' graft	1 pseudo	15 consolidated	
Schulitz	1967	14	peripheral paralysis (6) spastic paralysis (1) arthrosis (2) chronic arthritis (3) tuberculosis (1) haemangioma (1)	tibial graft	2 late graft fractures	12 good (conc manual function, strength, pain)	
Schwarz	1967	13	cerebral palsy (4) polio (1) post-traum arthrosis (5) radial nerve lesion (3)	radionavic arthrodesis with spongy bone	1 pseudo	12 good (as regards pain + grip) 1 bad	

TABLE 28 (cont.) *RESULTS*

Author	*Year*	*Number*	*Indication*	*Technique*	*Complic remarks*	*Evaluation*	*Evaluation criteria*
Haddad	1967	24	arthrosis lunatomalacia scaphoid necrosis	iliac graft + Steinmann transfix pin	1 pseudo due to graft fracture	23 consolidation	
Dupont	1968	140	rheumatoid arthritis	distal ulna or iliac graft	8 pseudos (6%)	122 good (87%) 18 bad (13%)	
			Good = bony fusion + increased grip strength + patient free of pain and manual function improved Bad = if one of these criteria not fulfilled				
Pipkin	1968	9	polio (2) spast paralysis (1) post-traum paralysis (1) post-traum lesion (2) congenital lesion (2) tuberculosis (1)	Gill's method + Kirschner wire transfixation (4) other techniques (5)	2 pin problems	9 consolidations	
Straub	1969	18	rheumatoid arthritis	distal ulna/dist radius, both with Kirschner wire fixation	1 pseudo	subjective objective very good 11 13 good 4 4 fair 2 – bad 1 1	
			Subjective = patient's judgement 0-100 points as regards pain attenuation, grip strength, A D L Objective = in regard to pain attenuation, functional improvement, correction of deformity, reduced synovitis, solid fusion 75 - 100 points = very good 50 - 75 = good 25 - 50 = fair 0 - 25 = bad				
Ricklin	1970	12	scaphoid pseudo (6) lunatomalacia (4) post-traum wrist damage (2)	radiocarpal cartilage resection + spongy bone plasty		7 good 3 fair	in regard to pain, function and strength
Carroll	1971	27	rheumatoid arthritis	iliac graft + temporary wire fixation	1 pseudo	26 good 1 bad	according to Dupont + Vaini

TABLE 28 (cont.) *RESULTS*

Author	*Year*	*Number*	*Indication*	*Technique*	*Complic remarks*	*Evaluation*	*Evaluation criteria*
Mannerfelt	1971 1972 1973	124	rheumatoid arthritis (90) post-traum neurol lesion (31) congenital lesion (3)	several techniques + in 43 rheumatoid arthritis wrists personal technique using Rush nail	3 tibial fract (out of 19 donor sites) 2 median nerve problems, 1 infection and 2 pseudarthroses of the personal technique		
Rechnagel	1971	60	contractures paralyses lunatomalacia arthrosis	iliac graft (31) distal ulna (4)	16 pseudos		
Debeyre	1972	23	post-traum arthrosis (5) lunatomalacia (1) rheumatoid arthritis (10) tuberculosis (7)	iliac graft in split carpus	1 pseudo 2 pain in CMC joint	12 satisfied 3 unsatisfied 8 unknown	
Razemon	1972	19	scaphoid pseudo (13) perilunar dislocations (6)	iliac graft		18 good 1 bad	
Dreisilker	1973	10	rheumatoid arthritis (7) spastic paralysis (1) polio (1) tumour (1)	cartilage resection A O plate		all consolidated function good to fair	
Reichelt	1973	21	lunatomalacia (8) scaphoid pseudo (6) spastic paralysis (3) arthrosis (2) rheumatoid arthritis (1) tuberculosis (1)	various techniques	2 pseudos 1 radial fracture 1 infection	10 satisfied 6 patients much pain 3 patients impaired finger function	
Larsson	1974	23	rheumatoid arthritis (17) neurol (2) post-traum (3) arthrosis (1)	cartilage resection + A O plate	3x wound problems	all consolidated, grip strength improved in all	

TABLE 28 (cont.) *RESULTS*

Author	*Year*	*Number*	*Indication*	*Technique*	*Complic remarks*	*Evaluation*	*Evaluation criteria*
Millender	1975	70	rheumatoid arthritis	cartilage resection + Steinmann pin	2 pseudos 1 infection 12 pin migrations 3x wound necrosis	grip strength and function improved in all patients	
Manetta	1975	5	post-traum lesion	radiocarpal cartilage resection + A O plate		all cosolidated	
Weigert	1975	12	chronic arthritis (8) scaphoid pseudo (3) post-traum lessions (1)	cartilage resection iliac spongy bone A O plate	4 wound problems	all consolidated	
Linclau	1975	31	post-traum arthr (8) lunatomalacia (5) rheumatoid arthritis (1) tuberculosis (1) spastic hemiplegia (7) *polio* (3) nerve lesion (4) Volkmann (2)	modified Brittain with bone homograft	1 pseudo	27 satisfied 26 good 4 fair 1 bad	
			Evaluation criteria Linclau Good = clin + radiol solid, obj + subj function improved, no pain Fair = subject symptoms without object causes Bad = no arthrodesis or no objective functional improvement				
Bamert	1977	30	arthrosis (12) rheumatoid arthritis (11) paralyses (2) tumour (1) lunatomalacia (2)	iliac graft + A O plate	2 pseudos 2 tendon lesions 1 ulnar problem 1 iliac infection	of 18 pat , 15 free of pain	

TABLE 28 (cont.)

RESULTS

Author	*Year*	*Number*	*Indication*	*Technique*	*Complic remarks*	*Evaluation*	*Evaluation criteria*
Hörster	1977	20	post-traum lesion	cartilage resection, iliac spongy bone + A.O plate		all consolidated	
Makin	1977	34	polio (28) brachial plexus lesion (2) spastic paralysis (4)	iliac graft in split carpus	2 pseudos due to graft dislocation + infection	32 consolidated	
Mikkelsen	1980	59	rheumatoid arthritis	modified Mannerfelt method	3 pin problems 2 pseudos	57 consolidated	
Clendenin	1981	31	arthrosis rheumatoid arthritis neurol abnormalities	several techniques	6 pseudos 1 infection 2 fractures 5 wound necrosis		
Narr	1982	20	scaphoid pseudo (7) post-traum (5) tuberculosis (2) rheumatoid arthritis (1) lunatomalacia (1) arthrosis (3)	iliac graft + A O plate	1 pseudo 1 infection 3 tendon adhesions 1 wound necrosis	19 consolidated all patients free of pain	
Papaioannou	1982	12	rheumatoid arthritis	carpal + distal ulnar chips + Steinmann pin	3 pseudos 4 pin migrations to distal	subjectively, 11 free of pain 12 functional improvement 8 increased strength	

TABLE 28 (cont.) *RESULTS*

Author	*Year*	*Number*	*Indication*	*Technique*	*Complic remarks*	*Evaluation*	*Evaluation criteria*
Rayan	1982	19	post-traum arthrosis (7) unsuccessful carpal arthroplasty (2) spastic paralysis (2) flaccid paralysis (1) arthrosis (1) Reiter (1) unknown (5)	intercarpal fusion using spongy bone + iliac graft + screws		13 excellent 1 fair 5 not followed up, all consolidated	score 0-100 points – pain – mobility – function – radiol appearance – subjective judgement therefore 5x0-20 points

Pain
No pain or discomfort in cold (20)
slight pain during heavy work
discomfort in mild cold responding to aspirin (15)
severe pain, only during heavy work (10)
severe handicapping pain constantly present (0)

Mobility
No mobility in arthrodesis tract No functional impairment in the other joints (20)
any impairment in pronation, supination or finger function (10)
mobility in arthrodesis tract (0)

Manual function
postoperatively improved (20)
unchanged (10)
deteriorated (0)

Radiological appearance
no pseudarthrosis, no graft fracture
No deformity in the arthrodesis tract (20)
deformity in the arthrodesis tract (10)
pseudarthrosis or graft fracture (0)

Patients' judgement
Highly satisfied (20)
satisfied (10)
not satisfied (0)

Author	*Year*	*Number*	*Indication*	*Technique*	*Complic remarks*	*Evaluation*	*Evaluation criteria*
Skak	1982	24	rheumatoid arthritis (20) arthrosis (4)	Mannerfelt's method	4 MC fractures 4 wound problems	all consolidated 5 mild pain during function 17 function subjectively improved	

Studying this review, we note that most authors have not applied or described any evaluation criteria and have restricted themselves to the difference between consolidation and pseudarthrosis, the patient's assessment and/or the assessment of the follow-up examiner.
Only Merle d'Aubigné (1956), Dupont (1968), Straub (1969), Linclau (1975) and Rayan (1982) have applied clearly defined evaluation criteria to their patients (with marked similarity of the criteria of Dupont and Straub and mostly of Linclau as well). Still, the evaluation schemes described have all been limited to subjective assessment of functional value and to the motion functions of the limbs in question. None of the authors has confronted the patients with clearly defined activities with a view to qualitative and quantitative evaluation of function. In addition, the series of Dupont and Straub (1969) consist exclusively of patients with rheumatoid arthritis, and the series described by Rayan (1982) and Linclau (1975) are far smaller. Where number of patients and indication range are concerned, the series of Merle d'Aubigné (1956) corresponds best to our study.
In order to obtain at least some degree of comparability, we have assessed the results of this follow-up also by the criteria applied by Merle d'Aubigné, Dupont, Linclau and Rayan (cf. pages 83, 86, 88 and 90).

VII.2. The subjective result - assessment by the patient

To render this assessment possible, the patient was invited to distinguish between his postoperative and his preoperative condition in regard to factors affecting use of the hand (pain, reduced strength, lack of ability to grip an object firmly, feelings of instability, specific functions and other disorders - see also pages 51, 52. If necessary, the findings were then correlated with relevant data in the clinical files.

The results are shown in tables 29-33 below

TABLE 29

	pre-op.	*post-op.*	*pre- en post-op. symptom-free*	*improved*	*un-changed*	*reduced*
a. pain	46	25	18	38	8	2*
b. strength reductors	59	9	4	53	8	1
c. firm grip impossible	47	23	13	30	17	6
d. instability	49	11	14	41	8	3 (n=66)

* These patients were free of pain before operation.

Only two patients had preoperatively been normal in regard to all four parameters mentioned above. At follow-up, this number proved to have increased to 31 (47%).

The combination of all four abnormalities, i.e. pain, reduced strength, lack of firm grip and instability had preoperatively existed in 28 patients (42.4%) (Group I: 8; Group II: 12; Group III: 7; Group IV: 1). At the time of the follow-up, this fourfold combination still existed in only 5 patients (Group I: 3; Group II: 1; Group III: 1).

In regard to *pain*:

Eighteen patients were free of pain both preoperatively and at follow-up; postoperatively, pain had disappeared in 23, decreased in 15, remained unchanged in 8 and newly developed in 2 patients.

TABLE 30

pain

			postoperatively		
preoperative	*none*	*little*	*moderate*	*severe*	*total*
none	18	2	–	–	20
little	3	–	–	–	3
moderate	6	–	1	–	7
severe	14	10	5	7	36
	41	12	6	7	66

In regard to *strength or reduction of strength:*

The shifts of strength are shown in Table 31.

TABLE 31

strength

		postoperative		
preoperative	*same as other side*	*less than other side*	*more than other side*	*total*
same as other side	4	1	2	5
less than other side	22	8	29	59
	26	9	31	66

TABLE 32

Concerning firm grip:

		postoperative	
preoperative	*absent*	*present*	*total*
absent	17	30	47
present	6	13	19
total	23	33	66

In other words, 30 patients who preoperatively had not had a firm grip, had acquired one after operation, but 6 who had had a firm grip before, had lost it after operation, i.e. they were deteriorated.

Instability
Pre- and postoperative instability were also compared:

TABLE 33

Instability

		postoperative	
preoperative	*absent*	*present*	*total*
absent	14	3	17
present	41	8	49
total	55	11	66

We found that 41 patients had had sensations of instability before operation, which were abolished by surgery, but that three patients who had had no such sensations had acquired them postoperatively.

Specific functions and preferential use
Ability to perform A.D.L. (described on page 51) was much improved after operation. Whereas preoperatively, 56 patients had had preference shifts, such shifts were reported by only 46 at follow-up. Moreover, in 34 of these 46 the *number* of actions for which preference was shifted was found to have decreased. This implies that these patients functioned better with their operated hand than before the operation. However, this improvement should

not be attributed exclusively to the surgery: the patient's adjustment to his handicap with the passage of time has probably played a not insignificant part in this respect.

Other complaints

Patients were unable to compare postoperative sensations grouped under this heading with corresponding preoperative feelings.

The fact remains, however, that 35 of the 66 patients, or 53%, still mentioned sensations of this nature.

Patients' final assessment

Ultimately, patients were asked, without reference to evaluation criteria, whether they regarded themselves as improved, unchanged or worse. 53 (80.3%) reported improvement, 6 (9.1%) considered themselves unchanged and 7 (10.6%) deteriorated.

To conclude it should be mentioned that where the subjective result was concerned, there was no difference of any kind between the 8 patients in whom a pseudarthrosis was observed and the 58 with an ankylotic wrist joint.

VII.3. The objective evaluation

VII.3.1. Clinical and radiological evaluation of the surgical results

The clinical follow-up examination revealed that of the 66 operated wrist joints, 58 were ankylotic and 8, pseudarthrotic. At the time of cast removal, these figures were 52 and 14, respectively; of these 14, 4 became ankylotic after reoperation.

As regards the position in which the wrist joint had become ankylotic, evaluation according to our criteria (see pages 54 and 55) showed:

- a good to very good wrist position in 35 patients (60.3%)
- a fair wrist position in 16 patients (27.6%)
- an unacceptable wrist position in 7 patients (12.1%).

It should be kept in mind that wrist positions classified as fair, good or very good all come into the category defined in the literature as functional position(s), so that this criterion is fulfilled by *87.9%* of the ankylotic wrists. At clinical examination, the arthrodesis tract proved painless in 41 patients. The strength of hand and finger muscles had clearly improved, as Table 34 shows, except in group IV in which some patients were improved and some deteriorated; when grip force is considered separately, the positive effect is slightly less. The mobility of hand and fingers, elbow and shoulder joint and the strength of the elbow and shoulder musculature hardly differed from the preoperative values. Pronation-supination mobility was deteriorated in 7 patients. However, all these patients belonged to indication groups III and IV, i.e. patients with more extensive pathology, so that this deterioration should not be interpreted as due exclusively to the arthrodesis operation. In indication groups I and II, pronation-supination, on the contrary, had returned to normal in 8 patients (Table 34).

TABLE 34

	group I		*group II*		*group III*		*group IV*		*total*	
muscle strength hand/finger musc.										
normal	3	**11**	5	**18**	4	**15**	–	**5**	12	**49**
partially impaired or reduced	9	**1**	*13*	**–**	14	**2**	13	**1**	49	**4**
a-functional	–	**–**	–	**–**	–	**1**	5	**12**	5	**13**
grip strength										
normal	–	**5**	4	**12**	1	**9**	1	**4**	6	**30**
partially impaired reduced	12	**7**	14	**6**	16	**8**	14	**11**	56	**32**
none	–	**–**	–	**–**	1	**1**	3	**3**	4	**4**
mobility hand/fingers										
normal	11	**11**	18	**17**	11	**13**	–	**2**	40	**43**
partially impaired or reduced	1	**1**	–	**1**	7	**5**	16	**14**	24	**21**
a-functional	–	**–**	–	**–**	–	**–**	2	**2**	2	**2**
elbow function impairment										
normal (0%)	12	**12**	18	**18**	15	**15**	5	**5**	50	**49**
slight (1-30%)	–	**–**	–	**–**	3	**1**	5	**6**	8	**7**
moderate (31-60%)	–	**–**	–	**–**	–	**2**	1	**–**	1	**2**
severe (61-90%)	–	**–**	–	**–**	–	**–**	2	**3**	2	**3**
a-functional (91-100%)	–	**–**	–	**–**	–	**–**	5	**4**	3	**4**
elbow musculature										
normal	12	**12**	18	**17**	17	**16**	3	**8**	50	**56**
partially impaired or reduced	–	**–**	–	**1**	1	**2**	13	**6**	14	**9**
a-functional	–	**–**	–	**–**	–	**–**	2	**4**	2	**4**

TABLE 34 (cont.)

	group I		*group II*		*group III*		*group IV*		*total*	
shoulder function impairment										
normal (0%)	12	**12**	18	**18**	17	**17**	7	**6**	54	**53**
slight (1-30%)	–	**–**	–	**–**	1	**1**	2	**4**	3	**5**
moderate (31-60%)	–	**–**	–	**–**	–	**–**	1	**–**	1	**–**
severe (61-90%)	–	**–**	–	**–**	–	**–**	5	**5**	5	**5**
a-functional (91-100%)	–	**–**	–	**–**	–	**–**	3	**3**	3	**3**
shoulder musculature										
normal	12	**12**	18	**18**	18	**15**	7	**9**	55	**54**
partially impaired or reduced	–	**–**	–	**–**	–	**3**	9	**7**	9	**10**
a-functional	–	**–**	–	**–**	–	**–**	2	**2**	2	**2**
impairment of pronation-supination										
normal (0%)	6	**10**	13	**17**	9	**6**	1	**2**	29	**35**
slitht (1-30%)	6	**2**	5	**–**	2	**6**	4	**3**	17	**11**
moderate (31-60%)	–	**–**	–	**1**	2	**5**	2	**3**	4	**9**
severe (61-90%)	–	**–**	–	**–**	3	**–**	6	**4**	9	**4**
a-functional (91-100%)	–	**–**	–	**–**	2	**1**	5	**6**	7	**7**

Roman =preoperative
Bold =follow-up

Classification of the cases with preoperatively impaired pronation-supination function as normalized, improved but still impaired, unchanged and deteriorated gave the following subdivision:

TABLE 34A

normalized	**4**	**4**	**1**	**2**	**11**
improved but still impaired	**2**	**–**	**2**	**4**	**8**
impairment unchanged	**–**	**–**	**6**	**8**	**14**
deteriorated	**–**	**1**	**4**	**3**	**8**

When we consider the 8 patients with a pseudarthrosis separately, we find that, except where grip force is concerned, these do not differ from the 58 others. Grip force had returned to normal in 1 pseudarthrosis patient and had remained diminished in the 7 others.

VII.3.2. Evaluation of the radiological findings

The X-ray films made immediately postoperatively, at cast removal and at follow-up were measured and compared. As mentioned on page 59, the following angles were examined (see also Fig. 17, page 6;):
- the angles between the radius and MC II and between the radius and MC III, both measured in the anteroposterior projection, and the angle of dorsiflexion , i.e. the angle between the radius and MC III measured in the lateral projection.

As mentioned before, the angles in the wrist joint measured in the X-rays and externally differ by less than 5°.

Degree of consolidation

Of 66 operated wrist joints, 58 were clinically judged ankylotic at follow-up. The X-ray failed to reveal bony union in 10 of these 58 joints, in which, therefore, there existed a fibrous ankylosis. Occurrence of this phenomenon after wrist arthrodesis has previously been reported by Merle d'Aubigné in 1956 and by Stjernwärd in 1964.

This gives the following classification:
- consolidated wrist joints: 48
- fibrous-ankylotic wrist joints: 10
- pseudarthrotic wrist joint: 8 (see also Fig. 16, page 48).

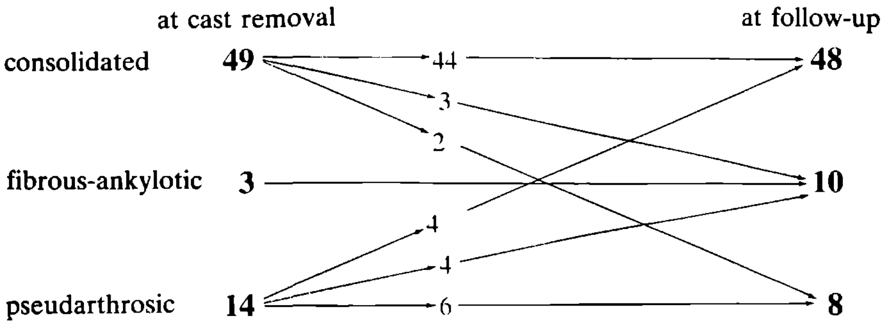
(Analysis of the radiological findings at follow-up, see page 59, brought to light an interruption of the bony union in 15 cases. According to the above date, this number should have been 18. Accordingly, in 3 cases the radiological examination had been performed or interpreted incorrectly.)

At the time of removal of the cast (see page 47), these figurs had been 49, 3 and 14, respectively.

Of the 49 wrist joints consolidated at cast removal, 3 were found at follow-up to have become fibrous-ankylotic and 2 mobile, i.e. pseudarthrotic, with loss of the consolidation (one after 'mobilization' by a physiotherapist).

The 3 fibrous ankyloses present at cast removal were still present at follow-up. Of the 14 joints with pseudarthrosis at cast removal, 4 spontaneously became ankylotic, 4 developed bony union after reoperation and 6 remained clinically and radiologically unchanged.

See the figure below.



* one of these after physiotherapeutic ‘mobilization’
** after reoperation.

Fig. 23 Change of the degree of consolidation between cast removal and follow-up

Subdivision of the ultimate degree of consolidation over the indication groups gives the following result:

TABLE 35

	group I	*group II*	*group III*	*group IV*	*total*
consolidated	4	14	15	15	48
fibrous ankylosic	4	3	2	1	10
pseudarthrosic	4	1	1	2	8
	12	18	18	18	66

This shows that the tendency to consolidation had been distinctly less in group I. In the literature we have found no references to this tendency in scaphoid pseudarthrosis. We also find that where the occurrence of fibrous ankylosis or of pseudarthrosis is concerned, there exists no difference between wrists operated with a tibial c.q. an iliac graft.

Interruption of the bony union

Absence of bony union (i.e. in the fibrous-ankylotic and pseudarthrotic wrist joints) proved to be localized mostly at the carpometacarpal level: in 13 of the 17 cases at the time of cast removal and in 12 of the 15 at follow-up.

Extent of the arthrodesis: Graft fusion and carpal fusion

Examination of the X-ray films at the time of cast removal (i.e. 3 months, on the average, after operation), revealed distinct fusion of the graft proximally.

Distally, at cast removal, a few grafts still only showed moderate fusion, most grafts subsequently fused better but a few were found at follow-up to have become loose at the distal end (see Table 36).

TABLE 36

Graft fusion

	none	*moderate (=<50%)*	*good (=>50%)*	*complete*	*total*
proximal	1 **–**	12 **–**	49 **3**	0 **59**	62
distal	5 **8**	3 **3**	12 **2**	42 **49**	62

Roman = at cast removal
Bold = at follow-up

If we consider the fusion of the carpal bones at the time of cast removal column by column (see also page 61) and compare the findings with those obtained at follow-up, the following figurs emerge:

TABLE 37

Carpal fusion

	column 1		*column 2*		*column 3*	
	cast removal	**follow up**	cast removal	**follow up**	cast remaval	**follow up**
none	13	**4**	7	**2**	48	**30**
partially	43	**48**	28	**10**	7	**9**
complete	10	**10**	31	**53**	11	**27**

Change of position of the arthrodesis and analysis by graft type

Classification and comparison of those wrist joints in which consolidation had been brought about with a tibial c.q. an iliac graft, ought to reveal any differences (Figs 24 and 25).

In order to render correct comparison possible, the following categories were excluded:

1. The entire neurological group, since this contains patients with flaccid as well as with spastic paralyses, so that the forces acting on the arthrodesis tract were (too) strong and could not be defined clearly
   Also, it was precisely in this group that the X-ray films often could not be interpreted and measured adequately (18 wrists).
2. surgical techniques without use of a tibial or iliac graft (7x)
3. cases in which the X-ray data were incomplete or unreliable (3x)
4. cases of pseudarthrosis (8x)
5. those cases in which the X-ray failed to show bony continuity (15x).

This selection left 32 wrists of groups I, II and III, of which 15 had been *ankylosed* by means of a tibial, and 17 by means of an iliac graft.

These two groups did not differ significantly in regard to duration of immobilization and follow-up period.

There were significant* differences in the angles of dorsiflexion, the radius-MC II angles and the radius-MC III angles as measured immediately after operation, at removal of the cast and at follow-up; these differences allowed the following conclusion:

'There occurs an unmistakable change of position of the hand in the palmar and ulnar directions, in tibial graft wrists as well as in iliac graft wrists' (Fig. 26).

However, these two categories differ from each other as well:**

- the total loss or change of dorsiflexion from postoperative to follow-up amounted to 4.47° for the tibial graft wrists ($P < 0.05$), as against 8.59° for the iliac graft wrists ($P < 0.001$), in other words, almost twice as much (1.92x) in the iliac as in the tibial graft wrists. (This constitutes an indication of significance, $P = 0.063$).
- the total shift in the ulnar direction between postoperative and follow-up, determined by measuring the angle between the radius and MC II amounted to 3.87° in the tibial graft wrists ($P < 0.05$) and to almost twice as much (1.88x) in the iliac graft wrists viz. 7.18°: This difference between tibial graft wrists and iliac graft wrist arthroseses proved not to be significant, however.

* The changes of position were tested by means of Student's method for 'one and two sample test' respectively
Levels of significance. $P < 0\ 05$ = significant
$0\ 05 < P < 0\ 10$ = indication of significance
$P > 0\ 10$ = not significant

** Figures mentioned below refer to *mean* values.

The difference determined by measuring the angle between the radius and MC III in the tibial graft arthrodesis wrists amounted to 6.20° in all ($P < 0.01$) and to 5.88° in the iliac graft wrist joints ($P < 0.001$). In this respect there is only a small difference between tibial and iliac graft wrist joints, which may be explained by the fact that during the operation, MC III is attacked less extensively than MC II. These values were also determined separately for the immobilization period and the period between cast removal and follow-up, which resulted in the following survey:

TABLE 38

change of dorsiflexion

– tibia	: total change	: 4.47° ($P < 0.05$)
	while in cast	: 2.93° ($P < 0.05$)
	from cast removal to follow up	: 1.53° ($P > 0.10$)
– ilium	: total change	: 8.59° ($P < 0.001$)
	while in cast	: 6.41° ($P < 0.001$)
	from cast removal to follow up	: 2.18° ($P < 0.05$)

Mean values.

in other words, in tibial graft wrists the change of position during the period in the cast was twice as much as that during the subsequent period.
In the iliac graft wrists, the change during the period in the cast even amounted to three times the change during the subsequent period.

Comparison of the tibial and iliac graft wrists in regard to the change of dorsiflexion during the immobilization in plaster revealed a significant difference: $P < 0.05$. In the period between cast removal and follow-up there is *no* significant difference between tibial and iliac graft wrists. For the postoperative period as a whole there is an *indication* of significance of the difference between tibial and iliac graft wrist: $0.05 < P < 0.10$ (see also Fig. 27).

Fig. 24 Patient operated following Brittain's technique: using a tibial graft with two additional small grafts in the carpal region (anteroposterior projection)

A: immediately after operation

B: at removal of cast (4.5 months p.o.)

C: at follow-up (10 years after cast removal) The fusion of the carpal bones includes column 1 and part of column 2, with hardly any progression between times B and C. The tibial graft can still be distinguished clearly.

continued

Fig. 24. (cont.)

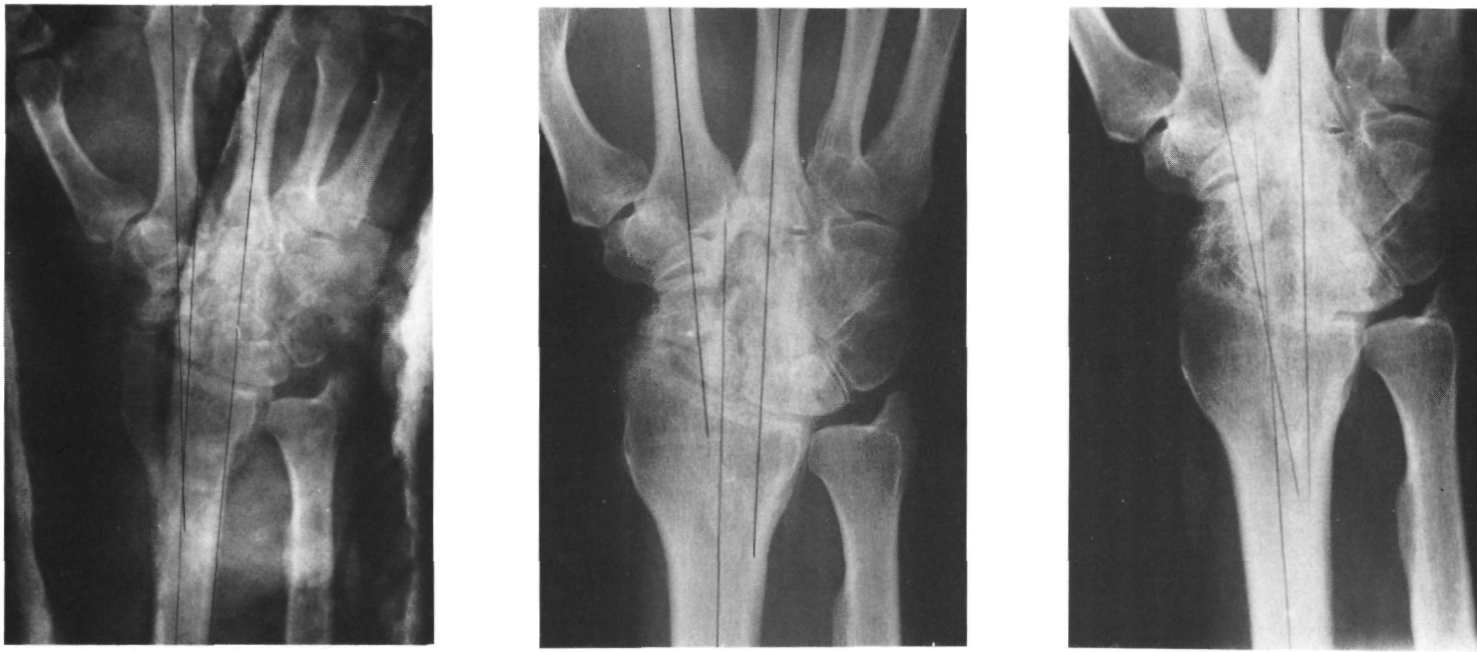
A: immediately after operation

B: at removal of cast

C: at follow-up

Brittain's technique (lateral projection)

Fig. 25. Patient operated according to Buttler's technique with graft from iliac crest



A: immediately after operation

B: at removal of cast (5 months p.o.)

C: at follow-up (9 years after cast removal) The fusion of the carpal bones includes columns 1 and 2 completely. The iliac graft can no longer be distinguished.

Fig. 25. (cont.)

A: immediately after operation

B: at removal of cast

C: at follow-up

Butler technique (lateral projection)

Fig. 26. Change of position in patient operated according to Butler's technique. A and A1 show the position at cast removal, B and B1 the position at follow-up. Comparison of A and B reveals a change of position, in the ulnar direction, of the position of the hand in relation to the forearm. Comparison of A1 and B1 shows the change of position in the palmar direction. The interval between cast removal (A, A1) and follow-up (B, B1) amounted to 6 years and 2 months.

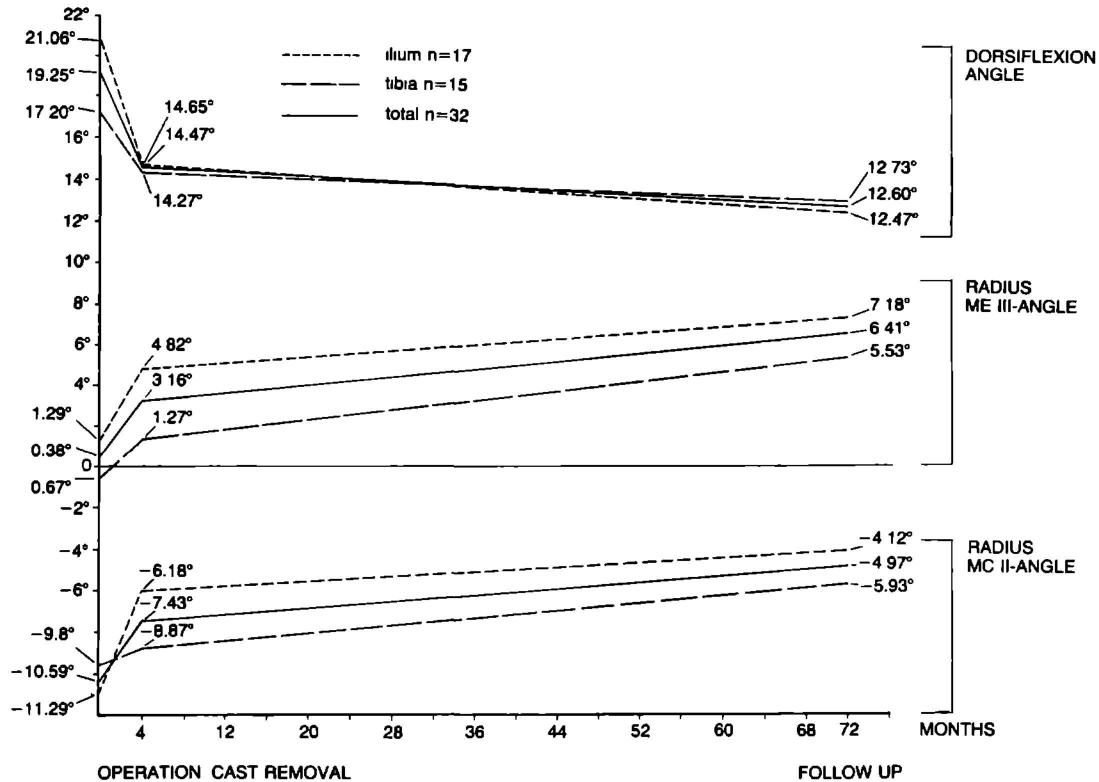


Fig. 27. Change of position determined by measuring the angle of dorsiflexion (radius – MC III angle) and radius – MC II angle and radius – MC III angle subdivided by tibial graft arthrodeses, iliac graft arthrodeses and both groups combined.

Change of ulnar deviation

As mentioned, this was calculated from the angles between the radius and MC II and the radius and MC III in anterolateral X-rays. The findings are listed below:

TABLE 39

Angle between radius and MC II

– tibia	: total change	: 3.87° ($P < 0.05$)
	while in cast	: 0.93° ($P > 0.10$)
	from cast removal to follow up	: 2.93° ($P < 0.02$)
– ilium	: total change	: 7.18° ($P < 0.001$)
	while in cast	: 5.12° ($P < 0.01$)
	from cast removal to follow up	: 2.06° ($P = 0.059$)

Mean values.

TABLE 40

Change of arthrodesis angles measured in x-rays, in degrees.

A *Group I + II + III: (n=32)* *(tibia and ilium)*	*postoperative position*	*position at cast removal*	*position at follow up*
dorsiflexion angle	19.25 ± 7.59	14.47 ± 15.52	12.60 ± 6.90
radius – MC II angle	−10.59 ± 5.67	−7.43 ± 7.20	−4.97 ± 6.90
radius – MC III angle	0.38 ± 5.94	3.16 ± 6.23	6.41 ± 6.56

B	*difference between postoperative position and position at cast removal*	*difference between position at cast removal and postion at follow-up*
dorsiflexion angle	−4.78 ± 5.01	−1.88 ± 3.64
radius – MC II angle	3.16 ± 5.76	2.47 ± 4.52
radius – MC III angle	2.78 ± 5.46	3.25 ± 3.88

C	*Total change = difference between follow up position and postoperative position*
dorsiflexion	−6.66 ± 6.22
radius – MC II angle	5.63 ± 6.10
radius – MC III angle	6.03 ± 5.76

TABLE 41

	tibial graft (n=15)		
A[1]	*postoperative position*	*position at cast removal*	*position at follow up*
dorsiflexion angle	17.2 ± 7.08	14.27 ± 6.48	12.73 ± 7.86
radius – MC II angle	−9.08 ± 6.39	−8.87 ± 4.48	−5.93 ± 6.35
radius – MC III angle	0.67 ± 6.08	1.27 ± 3.39	5.53 ± 5.55

B[1]	*difference between postoperative position and position at cast removal*	*difference between position at cast removal and position at follow up*
dorsiflexion	−2.93±4.76	−1.53 ± 4.26
radius – MC II angle	0.93 ± 4.62	2.93 ± 4.32
radius – MC III angle	1.93 ± 5.46	4.27 ± 3.79

C[1]	**tibial graft** *total change=difference between postoperative position an position at follow up*
dorsiflexion	−4.47 ± 6.42
radius – MC II angle	3.87 ± 6.54
radius – MC III angle	6.20 ± 6.73

TABLE 42

	iliac graft (n=17)		
A[2]	*postoperative position*	*position at cast removal*	*position at follow up*
dorsiflexion angle	21.06 ± 7.77	14.65 ± 4.72	12.47 ± 6.17
radius – MC II angle	−11.29 ± 5.03	− 6.18 ± 8.72	−4.12 ± 7.43
radius – MC III angle	1.29 ± 5.85	4.82 ± 7.68	7.18 ± 7.42

B[2]	*difference between postoperative position and position at cast removal*	*difference between position at cast removal and position at follow up*
dorsiflexion	−6.41 ± 4.77	2.18 ± 3.09
radius – MC II angle	5.12 ± 6.08	2.06 ± 4.79
radius – MC III angle	3.52 ± 5.51	2.35 ± 3.84

C[2]	*total change=difference between postoperative position an position at follow up*
dorsiflexion	−8.59 ± 5.52
radius – MC II angle	7.18 ± 5.40
radius – MC III angle	5.88 ± 4.96

This shows that in the tibial graft wrists, the change of position is most pronounced (three times as much) during the period *after cast removal*, whereas the iliac graft wrists change position most (twice as much) *during* the period in the cast.

Where the angle between the radius and MC II is concerned, it is only *during* the period in the cast that there is a significant difference in this respect between tibial and iliac graft wrists ($P < 0.05$).

For the period as a whole, and for the period between cast removal and follow-up, there are no significant differences ($P > 0.10$) (see also Fig. 27, page 107).

TABLE 43 **angle between radius and MC III**

– tibia	: total change	: 6.20° ($P < 0.01$)
	while in cast	: 1.93° ($P > 0.10$)
	from cast removal to follow-up	: 4.27° ($P < 0.01$)
– ilium	: total change	: 5.88° ($P < 0.001$)
	while in cast	: 3.53° ($P < 0.05$)
	from cast removal to follow-up	: 2.35° ($P < 0.05$)

Mean values.

This reveals a lesser tendency to ulnar deviation than that found by measuring the angle between the radius and MC II, but this holds true only of the tibial graft arthrodeses, not of the iliac graft wrist joints.

Where the angle between the radius and MC III is concerned, the changes in the tibial and iliac graft wrists do not differ significantly from each other, either over the total period or over the period considered here ($P > 0.10$) (see also Fig. 27).

We further considered the angle between the bone graft and the radius as determined on the various examination dates (Table 44)) (see also Fig. 17, page 60).

TABLE 44 **graft-radius angle**

	postoperative		*at cast removal*		*follow up*	
radial	8	**4**	6	**3**	1	**0**
ulnar	2	**3**	3	**10**	1	**2**
neutral	5	**10**	6	**4**	0	**3**
no longer to be determined due to fusion					13	**12**
	15	**17**	15	**17**	15	**17**

Roman = tibia **Bold = ilium**

This table once more shows that the position of the graft in relation to the radius often changes slightly, in the ulnar direction; this change occurs more often in tibial graft wrists.
We also considered the position of the graft at the distal end, both immediately after operation and at cast removal (Table 45).

TABLE 45

	distal carpal row	*MC II*	*MC II + III*	*MC III*	*MC III + IV*	
tibia	1	5	1	8	0	15
ilium	2	0	9	3	3	17
						32

This shows that approximately one-half of the tibial grafts were placed in MC II and that approximately one-half of the iliac grafts reached MC II + MC III.

Graft fusion and carpal fusion classified by graft type
At follow-up, 11 of the 15 tibial grafts could still be distinguished clearly, as against only 1 of the 17 iliac grafts (see also Figs 24 and 25).
Carpal fusion could also be distinguished according to graft type. For the several carpal columns, classified by graft type, we found the following distribution:

TABLE 46

carpal fusion

	column I				*column II*				*column III*			
	removal cast		*follow up*		*removal cast*		*follow up*		*removal cast*		*follow up*	
none	0	**6**	0	**–**	3	**1**	–	**–**	14	**13**	13	**5**
partial	15	**5**	14	**11**	8	**4**	7	**–**	1	**1**	1	**4**
complete	0	**6**	1	**6**	4	**12**	8	**17**	0	**3**	1	**8**

Roman = tibia **Bold = ilium**

The above shows that at follow-up, carpal fusion in column I had increased very little compared with the situation at cast removal in the tibial graft wrists, in contrast to the iliac graft wrists. In column II, bone fusion continued after cast removal in tibial as well as in iliac graft wrists, but distinctly better in the latter: all iliac grafts brought about complete fusion of the middle column whereas approx one-half of the tibial grafts ultimately led to only partial fusion of this column. In the ulnar column, column III, fusion in tibial graft wrists had increased hardly perceptibly between cast removal and follow-up, whereas the iliac graft wrists here, also, showed pronounced progression of the fusion after cast removal.

To recapitulate

The view of those authors who believe that cancellous bone leads to better and/or faster fusion than cortical bone (Abbott, 1942; Miyajima, 1979) is confirmed by our own findings.

Grafts from the iliac crest showed faster and more extensive fusion of the arthrodesis tract as judged at the time of termination of the immobilization. Subsequent incorporation of the osseous material also proved better in the case of iliac grafts: these more frequently led to a homogeneous bone structure, whereas most of the tibial grafts remained distinguishable from the surrounding bone (viz. 18 out of 31 tibial grafts as against 1 out of 28 iliac grafts) (see also Figs. 24 and 25).

Tibial grafts, on the contrary, gave relatively better results in regard to the deterioration of the position:

Taking into account inaccuracies of measurement, we find that during the immobilization period as well as during the period between cast removal and follow-up, there exists an unmistakable tendency of the hand to change position in relation to the forearm, in the palmar and ulnar directions. This deviation was found to be less in wrists operated with tibial than in those operated with iliac grafts.

In view of this phenomenon, mention should be made of the observation of Makin (1977) who in three children with a wrist arthrodesis (indication: flaccid paralysis) observed development of flexion in the arthrodesis tract with the passage of time. He attributed this to the weight of the paralysed hand. We have found no further references in the literature to the possibility of gradually developing deviation.

VII.3.3. Subjective and objective results classified by degree of consolidation

When the 66 wrist joints, classified by the degree of consolidation (consolidated: 48; fibrous-ankylotic: 10; pseudarthrotic: 8) are analysed according to subjective and objective criteria, we find that where the subjective evaluation is concerned, there is no difference between consolidated and pseudarthrotic wrists. However, the 10 patients with a fibrous-ankylotic wrist joint *all* still had residual complaints and sensations of discomfort (see page 52) in the region in question. This contradicts observations by Rechnagel (1971) mentioned below.

Objective evaluation revealed no differences between consolidated and fibrous-ankylotic wrists, while the patients with pseudarthroses differed only where grip force was concerned (normal in one patient, persistently reduced in seven).

VII.3.4. Comparison of the surgical technique

The different data concerning the Brittain-Ely and Butler techniques are summarized in the table below:

TABLE 47

	Brittain-Ely		**Butler**
graft type	*tibia*		*crista iliaca*
number of pat. by indic. group	31		28
group I	6		6
group II	7		11
group III	5		8
group IV	13		3
graft fracture (compl.)	3		1
tibial fracture	6		irrelevant
consolidation time		equal	
pseudarthrosis at cast removal	8		6
id. at follow-up after reoperation	4		4
change of position		<	
pain at donor site	4		7
sensib. disorder at donor sites	3		3

Table 47 reveals no difference between the two techniques where the result of the arthrodesis is concerned. Study of the literature shows that Stjernwärd (1964) did not observe any difference, either, between arthrodeses performed with tibial (15) and iliac (9) grafts.

The proportion of *tibial fractures*, almost 20%, however, is larger than in the literature: Danielsson (1963) saw one such fracture in 17 cases (5.9%), Salenius (1965) two in 42 cases (4.8%) and Mannerfelt three in 19 donor legs (15.8%).

The proportion of pseudarthroses, also, is relatively high compared with data in the literature. Discounting reoperations, the number of pseudarthroses at follow-up would have amounted to 10, or 15.2%. Reoperations reduced this number to 8, or 12.1%. In the literature, the proportions of pseudarthroses range mostly from 0 to 25% (Liebolt, 1938; Papaioannou, 1982). Hazewinkel

(1962) is the only author who makes clear mention of symptoms at the donor site: residual disorders in the tibial region in 10 patients out of 26, or 38.4%. In our series, 11 patients mention pain at palpation and pressure (7 at the iliac and 4 at the tibial donor site). Accordingly, in the entire series, residual symptoms at the donor site were mentioned by 7 out of 28 patients (25%) with iliac grafts and 4 out of 31 (12.9%) with a tibial graft. None of the patients with radial sliding grafts reported such symptoms.

VI.3.5. Extent of the arthrodesis tract

On the one side, considering the ratio of radiocarpal: radiometacarpal = 8 : 54 no preference can be deduced according to statistical criteria. We may repeat, however, that all 8 pseudarthroses belonged to the 'radiometacarpal' group. On the other side, reports in the literature do appear to make it possible to arrive at an opinion concerning the extent of the arthrodesis tract. A partial radiocarpal arthrodesis, i.e. an arthrodesis of radius, scaphoid and lunate bone, would appear inadvisable on functional-anatomical grounds because studies of intercarpal mobility have revealed that fixation of the proximal carpal bones blocks the entire intercarpal mechanisms (see Chapter II.1.2).

In the literature it is stated both on functional-anatomical (Dubousset, 1981) and on clinical grounds, that if at all possible, C.M.C. IV and IV should be *excluded from* the arthrodesis (Wickström, 1954; Reichelt, 1973; Hörster, 1977; Kirschner, 1977; Narr, 1982).These authors base their view on the fact that inclusion of C.M.C. IV and V in the arthrodesis renders the metacarpus immobile, so that it is no longer able to adjust to differently shaped objects. The authors who state that the arthrodesis *should* include C.M.C. II and III, support this view with a number of arguments:

- Stjernwärd (1964) because he found in his series that of the 12 patients with a radiometacarpal arthrodesis, 5 could resume heavy labour, whereas none of the patients with a radiocarpal arthrodesis were able to do so
- Clayton (1965) because in rheumatic patients, muscular imbalance may lead to flexion deformities in the C.M.C. joints
- Schulitz (1967) because he agreed with M. Lange (1962) that this technique leads to better consolidation of the arthrodesis
- Reichelt (1973) because in his view, disorders that occur or persist after radiocarpal and intercarpal arthrodeses are due to compensatory increase of mobility in the C.M.C. joints. Since he never observed these disorders in the radiometacarpal arthrodeses, he asserts that C.M.C. II and III should be included in the arthrodesis
- Rechnagel (1971) arrived at the opposite conclusion on the basis of absence of residual symptoms in 10 out of 12 patients in whom the arthrodesis of the carpometacarpal joints had been unsuccessful; he therefore concluded that inclusion of the C.M.C. joints in the arthrodesis is unnecessary, and radiocarpal arthrodesis suffices. However, our study fails to confirm this

conclusion because all 10 patients with a fibrous ankylosis in the C.M.C. region had residual manual and/or carpal symptoms.

The merits of the intercarpal arthrodesis are not entirely clear. This operation is performed exclusively in local pathology in the carpus (usually scaphoid pseudarthrosis or lunate bone necrosis), provided the radiocarpal joint is still intact. As mentioned above, Reichelt (1973) encountered residual symptoms in these cases and Graner (1966) observed development of a radiocarpal arthrosis after a few years in 4 out of 38 (10.5%) of carpal joints treated in this manner.

VII.3.6. Evaluation of the functional result

Since we have not found any description in the literature of any method of ergonomic evaluation of the effect of a wrist joint arthrodesis on manual function, we have devised such a method ourselves. To this purpose, use was made of evaluation methods from hand and rheumatoid surgery. Much value was also attached to the empirical criteria applied in ergotherapy: on the basis of clinical experience and good insight into A.D.L. and grip pattern, it appeared possible after all to devise an ergonomic evaluation method permitting comparable and reproducible testing of our patients. Since no ergonomic follow-up of patients with a wrist joint arthrodesis has been carried out ever before, we were unable to compare our findings with those of others.

The ergonomic evaluation method proved to be an efficient technique to assess the degree to which the function of the upper extremity, and hand function in particular, was impaired by the primary pathology (and the treatment).

Our findings do not justify the conclusion that the ergonomic evaluation as performed by us provides any information on the degree of success of the arthrodesis from the orthopaedic-technical or clinical points of view: there were no significant differences in scores of patients in whom the arthrodesis, considered clinically, had not been achieved, and of patients in whom a fibrous ankylosis had been achieved. This leads to the conclusion that the question whether or not a consolidated arthrodesis (with bony union) is accomplished does not affect the ultimate functional result.

The observation that a good ergonomic score might be achieved even with a wrist position outside the range of 'functional positions' suggests that the '*optimum position of function*' cannot be established with the aid of these ergonomic criteria, a view shared by Clayton (1965); Dupont (1968) and Pryce (1980).

We found that patients with only local pathology of the wrist joint (the scaphoid and lunate bone groups) ergonomically scored distinctly better than the arthrosis-arthritis patients and the patients of the neurological group (the latter scoring lowest). In other words, the more extensive the affection of the locomotor apparatus, the lower the ergonomic score. Our findings fail to indicate whether more importance should be attached to the functional value or to compatibility with the body scheme.

An analysis of the pattern of shifts of preferential use showed that the proportions of shifting were largest for activities requiring greater strength, in other words, a power grip (handling screw tops, corkscrew and can opener; 48%, 32% and 30%, respectively).

We may conclude from these findings that the ergonomic evaluation method applied appears suitable for pre- as well as postoperative analysis of patients with lesions described above. In combination with the clinical and radiological evaluation, it may provide an overall picture of indication, operation and results to be expected.

VII.3.7. Occupational aspects

In as far as could be determined, the possible effect of the arthrodesis on the occupation had not been evaluated preoperatively in a single patient. There were four patients whose symptoms occurred mostly during work. After arthrodesis, one of these could resume his former job, one had to do different work and two were unable to find a suitable job. Nevertheless, from the clinical material there emerges a favourable effect of the wrist arthrodesis from the occupational point of view: the number of completely disabled subjects decreased from 40 to 19, and the number of those judged completely fit to work increased from 1 to 21. It should be noted, however, that this effect was minimal in the patients with a scaphoid pseudarthrosis (see pages 74, 75). However, in this group we have four patients with a pseudarthrosis and four with a fibrous-ankylotic wrist joint.

In spite of the surgical treatment, 36 patients were forced to resort to lighter work or to stop working completely. These 36 included 7 of 8 pseudarthrosis patients and 7 of the 10 patients with a fibrous-ankylotic wrist joint.

In 22 patients, the lesion had not directly affected the work. In 8 cases, the effect on the current work could not be established directly, although the patients were of the opinion that the lesion did not affect the work at all.

Judging by the criteria applied by G.A.K. and G.M.D. regarding wrist strain and wrist motion, 55-60% of the patients with a clinically ankylotic wrist joint were found to perform or to have performed equally heavy or even heavier work after the arthrodesis operation. In this respect it should be recalled that according to these criteria all the occupations in which our patients had functioned before operation ought to be still possible after a wrist joint arthrodesis (Offringa, 1976). This is in contradiction to our findings, which are also confirmed in the literature (Hazewinkel, 1962; Stjernwärd, 1964).

VII.4. Comparison of our overall results with those in the literature

From a comparison of our overall results with those reported in the literature, the fact emerges clearly that an arthrodesis of the wrist joint

should fulfil the following conditions:
- bony union
- subjective improvement of:
  pain
  strength
  firm grip
  stability
- no aggravation of loss of function in adjacent joints (of hand and forearm)
- a good to very good ergonomic score.

Application of these criteria to our series of patients reveals that these conditions are met by only 28 of the 66 patients = 42.4% (Group I: 4; Group II: 14; Group III: 8 and Group IV: 2). It should be remembered in this connection that in Group IV the operation was performed more often for cosmetic reasons, or to create a stable union between the forearm and hand, rather than primarily to increase functional value. (Discounting group IV, the proportion of success amounts to 54%.) Per indication group, the proportions of successful arthrodeses were:
Group I: 33.3%; Group II: 77.8%; Group III: 44.4% and Group IV: 11.1%.

We have also judged our own clinical findings according to the criteria laid down in the literature by Merle d'Aubigné (1956), Dupont (1968), Linclau (1975) and Rayan (1982) (see pages 83, 86, 88 and 90); the comparative findings are shown in the tables below.

According to Merle d'Aubigné's criteria (see page 83), pain, mobility and muscular strength compared as follows:

TABLE 48

	personal series	*Merle d'Aubigné series*
very good	29 (43.9%)	17 (33.3%)
good	11 (16.7%)	15 (29.4%)
fair	12 (18.2%)	11 (21.6%)
bad	6 (9.1%)	3 (5.9%)
very bad	8 (12.1%)	5 (9.8%)
	66 (100 %)	51 (100 %)

When we compare our findings with those of Dupont (see page 86), whose criteria were bony union, grip strength, pain and overall functional value of the hand as judged by the patient himself, we find the following figures (it should be recalled that Dupont's series consisted exclusively of rheumatoid arthritis patients):

TABLE 49

	personal series	*Dupont's series*
good	34 (51.5%)	122 (87%)
bad	32 (48.5%)	18 (13%)
	66 (100 %)	140 (100%)

Application of the criteria of Linclau (page 88) gives the results shown in Table 50 (here, again, the mobility function was judged objectively and improvement of function subjectively):

TABLE 50

	personal series	*Linclau series*
good	36 (54.5%)	26 (83.9%)
fair	12 (18.2%)	4 (12.9%)
bad	18 (27.3%)	1 (3.2%)
	66 (100 %)	31 (100 %)

Finally, evaluated according to Rayan's method (page 90)

TABLE 51

	personal series	*Rayan's series*
excellent	21 (31.8%)	12 (85.7%)
very good	19 (28.8%)	1 (7.1%)
good	13 (19.7%)	–
fair	2 (3.0%)	1 (7.1%)
bad	11* (16.7%)	–
	66 (100 %)	14 (99.9%)

i.e. good to excellent: 80% (Rayan: 93%)
bad : 17% (Rayan: none)

* This figure included 7 of the 8 pseudarthroses.

It should be pointed out in this respect that with this method, parameters were compared that were strongly correlated: in case of failure of the arthrodesis, there will be not only mobility in the arthrodesis tract, but as a rule, radiological proof of a pseudarthrosis as well. Similarly, in case of severe residual pain, the patients' satisfaction will be correspondingly less.

We find that when we apply the criteria laid down in the literature, our own results are distinctly worse than those reported by the authors. Only Merle d'Aubigné's findings are in reasonably agreement with our own.

VII.5. Conclusions and recommendations

1. In view of the subjective results (pain, force, grip strength and instability improved on 80,3%, unchanged in 9,1% and deteriorated in 10,6%), the indication for wrist joint arthrodesis proves to have been correct.

2. The Brittain-Ely technique and the Butler technique give identical clinical and ergonomic results.

3. When the Brittain-Ely technique is used, the risk of a fracture of the donor tibia should not be ignored.

4. Grafts from the iliac crest lead to faster and more homogeneous bony union than tibial grafts.

5. Tibial grafts offer more resistance to forces that may lead to deterioration of the arthrodesis angle.

6. Patients with a fibrous ankylosis at the carpometacarpal level may have a functional score as good as those with a consolidated wrist joint. However, in a fibrous-ankylotic wrist joint, residual symptoms may occur. An ankylotic wrist joint does not guarantee adequate function, while on the other hand, a good ergonomic function score may be obtained by a patient with a pseudarthrosis.

7. The fact that patients with different positions of the hand in relation to the forearm obtained equal functional scores justifies the assumption that a *generally valid* 'optimum position of function' cannot be established. It should be determined ergonomically for each individual patient.

8. In a patient to be subjected to arthrodesis of a wrist joint, a pre- and postoperative ergonomic inventory, and ergotherapeutic after-treatment are always advisable. To this end, use may be made of the ergonomic evaluation method devised for this investigation.
   The preoperative analysis should be concerned not only with the A.D.L.,

but with occupational activities, as well. The indication depends in part on the latter factor.

9. It may be concluded from the literature that a radiometacarpal arthrodesis is to be preferred to a radiocarpal one; however, C.M.C. IV and V should be excluded from the arthrodesis in view of their importance for grip function.

Part I of this thesis contains the introductory chapters.

Chapter I introduces and describes the purpose of this study, viz. an evaluation of the result of arthrodesis of the wrist joint. The results have been evaluated clinically, radiologically and ergonomically. To this purpose, 65 patients in whom 66 wrist joints had been operated, have been followed up. A method of ergonomic evaluation, suitable for qualitative and quantitative assessment of hand function after a wrist arthrodesis has been devised especially for this study.

Chapter II deals with the anatomy. Functional-anatomical descriptions are presented of the various articular levels of the wrist joint: the radiocarpal, the carpal and the carpometacarpal levels, as well as the metacarpophalangeal and interphalangeal articular levels. Attention is paid to the grip function of the hand. The various grips are described and analysed from the functional points of view, with detailed reference to the distinction between power grip and precision grip/handling. This followed by a detailed discussion of the 'functional position' of the hand in relation to the forearm, with reference to both the degree of dorsiflexion and the radioulnar abduction position.

In Chapter III, the indications for wrist arthrodesis are defined and classified as follows:
2 groups with only local pathology of the carpus (the 'scaphoid group' and the 'lunate bone group');
1 group with pathology of the entire carpus ('arthrosis-arthritis group');
1 group of pathological conditions which, although originating outside the wrist, manifest themselves in the wrist also. (Since this group consisted largely of patients with neurological pathology, it is called the 'neurological group').
This is followed by a survey of the surgical techniques described in the literature, including a paragraph on the use of bone grafts. This chapter ends with a list of the current alternatives to arthrodesis.

Part II contains the report of the follow-up of the patients.

In Chapter IV, the clinical material is presented: 65 patients with 66 wrist joints operated during the period 1961-1974 and followed up 1-14 years (average 6 years) after the operations.
According to the criteria described in Chapter III, the patients were divided into 4 groups as follows:
Group I - the scaphoid group: 12 wrists; Group II - the lunate bone group: 18

wrists; Group III - the arthrosis-arthritis group: 18 wrists; Group IV - the neurological group: also 18 wrists.
Subsequently, the data from the clinical files are analysed and arranged schematically. Reference is made to the functional impairment of the affected wrist joint and to a method of quantifying this functional impairment based on the J.A.M.A. (1958) impairment scale.
A detailed description is then given of the two most widely used surgical techniques, the Brittain-Ely method and the Butler technique. This is followed by a report of the surgical findings, the complications and the findings obtained at out-patient follow-up examinations.

Chapter V describes the clinical follow-up. This consisted of:
- an anamnestic evaluation
- an orthopaedic examination of the local and regional conditions, in the arthrodesis tract as well as at the donor site. Here, the concept of wrist score is introduced: an evaluation of the position in the ankylosed wrist joint, based on data from the J.A.M.A. impairment evaluation guide (1958).
- a radiological evaluation to determine the presence or absence of an interruption of the bony continuity, the anatomical level of this interruption, if any, the extent of the arthrodesis and the position in the arthrodesis of the metacarpus in relation to the distal radius.
- an ergonomic evaluation, carried out only in the patients with a unilateral lesion (61). Here, a method of evaluation is described with subdivision into four blocks in which the following functions can be examined:
- block 1: hand and finger function
- block 2: various grips, strength of extension and grip
- block 3: test programme for the function of the upper extremity
- block 4: bimanual specific functions.

The results obtained per block, the socalled *block scores* are then presented and analysed.
This includes a determination, based on the anamnesis, of any shifts in the patterns of preferential use. Thereafter, the ergotherapist determined to what extent the affected extremity was functionally useful and compatible with the body scheme. Finally, the stereognostic capacity was evaluated in all cases.

Chapter VI deals with aspects concerning the (in)capacity to work and the occupation. The pre- and postoperative occupations are compared, and the current occupation of the patients is analysed, with reference to concepts such as degree of wrist strain and of wrist motion. For this analysis, use was made of data supplied by labour experts of G.A.K. and G.M.D.

Chapter VII contains the discussion of the results. The introduction contains a detailed tabular review of the literature listing the authors (with years), numbers of patients, indications, surgical techniques and results (i.e. evaluation, evaluation criteria, complications and remarks). This review

shows that only 6 of the 51 authors have applied clearly defined criteria to evaluate the final results.
This is followed by a report of the results as judged subjectively by the patients: 80.3% regarded themselves as improved, 9.1% as unchanged and 10.6% as deteriorated, on the basis of such parameters as pain, instability, firmness of grip and strength. Residual symptoms were mentioned by 35 patients. In 34 (out of 56) patients, the pattern of preferential use had improved.
The objective evaluation begins with an analysis of the surgical result: of the 66 wrists, 58 showed bony ankylosis = consolidation and 10, fibrous ankyloses, while in 8 there existed a pseudarthrosis, i.e. mobility in the arthrodesis tract.These figures are compared with the findings at the end of the immobilization period.
We find that 88% of the ankylotic wrist joints had a position fulfilling the criteria applied in the literature to the 'functional position'.
At clinical examination, 41 patients were found to be free of pain, while 30 had a normal (grip) strength.
Radiological examination showed that most of the osseous defects in the pseudarthrosis region were localized at the carpometacarpal level (12 out of 15). Corticocancellous (iliac) grafts were found to lead to faster, more extensive and more homogeneous bony fusion than cortical (tibial) grafts. The latter, however, led to less deterioration of position, which was found to consist in deviation in the palmar and ulnar directions.
Comparison of the surgical techniques reveals no difference between arthrodeses brought about by means of tibial and of iliac grafts: both techniques led to the same proportions of consolidations, fibrous ankyloses and pseudarthroses. The incidence of fractures of the donor leg is high: almost 20% (6 out of 31). The proportion of pseudarthroses is also relatively high: 12% = 8 cases.
In the subsequent discussion of the extent of the arthrodesis tract, it might be concluded from the literature that a radiometacarpal arthrodesis including only C.M.C. II and III is to be preferred. In our material, however, this could not be confirmed because of incomparability of the figures.
In the discussion of the evaluation of the functional result, the fact clearly emerges that the question whether an arthrodesis should be regarded as successful or unsuccessful should be judged not only by orthopaedic-technical, but also by ergonomic criteria. The ergonomic evaluation, namely, shows that irrespective of the position of the hand in relation to the forearm in the wrist joint, the extremity may still be capable of reasonable to very good function, in which respect it appears irrelevant whether the arthrodesis is consolidated (with bony fusion) or fibrous-ankylotic, or even has not been accomplished at all.
Classification by indication group shows that patients from groups I and II have the best ergonomic scores, and group-IV patients the worst.

The value of this ergonomic evaluation method, applied both pre- and postoperatively, is emphasized.
In regard to work and occupation, the wrist arthrodesis proves to have a favourable effect: the number of subjects 100% unfit for work decreased from 40 to 19, and the number of those fit for work increased from 1 to 21. This effect was observed largely in indication groups II, III and IV.
Still, in spite of the surgical treatment, 18 patients were forced by their lesion to fall back on lighter work, and another 18 could no longer work at all.
Finally, the overall results have been evaluated according to personal criteria, viz.:
- bony union of the arthrodesis tract
- subjective improvement of pain, strength, firmness of grip and instability
- no increase of loss of function in adjacent joints of the hand and forearm
- a good to very good ergonomic score.

Only 28 of the 66 patients (42.2%) met all these conditions.
Judged by the less strict and more limited criteria applied by Merle d'Aubigné (1956), Dupont (1968), Linclau (1975) and Rayan (1982), the results in our series of patients proved to be clearly worse.
Our series corresponded best to that of Merle d'Aubigné (1956), both as regards indications and as regards numbers of patients, and to a lesser degree to the group of patients reported by Linclau (1975). The groups of Dupont (1968) - all of them rheumatoid patients - and of Rayan (1982) - only 14 cases - match our own series even less well.
To conclude, a number of conclusions and recommendations are advanced.

SAMENVATTING

Deel I van dit proefschrift bevat de inleidende hoofdstukken.

In hoofdstuk I wordt het doel van deze studie ingeleid en beschreven, n.l. een evaluatie van het resultaat van de arthrodese van het polsgewricht. Deze evaluatie is zowel klinisch, röntgenologisch alsook ergonomisch uitgevoerd. Hiertoe zijn 65 patiënten bij wie 66 polsgewrichten zijn geopereerd na-onderzocht. Voor deze studie is een ergonomische evaluatiemethode ontwikkeld om de handfunctie na een polsarthrodese kwalitatief en kwantitatief te kunnen beoordelen.

Hoofdstuk II is gewijd aan de anatomie. De verschillende gewrichtsniveaus van het polsgewricht: het radiocarpale, het carpale en het carpometacarpale niveau, evenals het metacarpophalangeale en de interphalangeale gewrichtsniveaus zijn functioneel anatomisch beschreven. Er wordt aandacht geschonken aan de grijpfunctie van de hand. De verschillende handgrepen worden beschreven en functioneel geanalyseerd, waarbij uitgebreid wordt ingegaan op het onderscheid tussen powergrip en precision grip/handling. Hierna volgt een uitgebreide verhandeling over de „functionele stand" van de hand t.o.v. de onderarm, waarbij zowel de mate van dorsaalflexie alsook de radioulnairabductiestand wordt besproken.

In hoofdstuk III worden de indicaties voor een polsarthrodese vernoemd en als volgt ingedeeld:

2 groepen waarbij de handwortel locaal is aangedaan (de „scaphoidgroep" en de „lunatumgroep").

1 groep waarbij de handwortel geheel is aangedaan (de „arthrodese-arthritisgroep").

1 groep van aandoeningen welke buiten de pols hun oorsprong hebben, maar zich ook in de pols manifesteren. (Omdat dit voornamelijk neurologische afwijkingen zijn, wordt deze de „neurologische groep" genoemd.

Hierna volgt een overzicht van de in de literatuur beschreven operatietechnieken, waaraan een paragraaf is toegevoegd over toepassing van bottransplantaten. Het hoofdstuk wordt besloten met een opsomming van de huidige alternatieven van een arthrodese.

Deel II is gewijd aan het patiënten-onderzoek.

In hoofdstuk IV wordt het patiëntenmateriaal gepresenteerd: 65 patiënten met 66 geopereerde polsgewrichten, geopereerd in de periode 1961-1974 en na-onderzocht 1 – 14 jaar na de operatiedatum (gemiddeld 6 jaar postoperatief).

De patiënten worden, volgens de in hoofdstuk III beschreven indeling in 4 groepen gerangschikt, hetwelk de volgende verdeling oplevert:
in groep I – de scaphoidgroep: 12 polsen; in groep II – de lunatumgroep: 18 polsen, in groep III – de arthrose-arthritisgroep 18 polsen en in groep IV – de neurologische groep eveneens 18 polsen.
De gegevens uit de patiëntenstatus worden vervolgens geanalyseerd en schematisch gerangschikt. Hierbij komt de functiebeperking van het betreffende polsgewricht ter sprake en wordt een op de J.A.M.A. (1958) invaliditeitsschaal gebaseerde methode gepresenteerd om deze functiebeperking te kunnen kwantificeren.
Hierna worden de twee voornamelijk toegepaste operatietechnieken – de Brittain-Elymethode en de Butlertechniek gedetailleerd beschreven. Vervolgens worden de operatiebevindingen, de complicaties en de gegevens uit de poliklinische controles vermeld.

In hoofdstuk V wordt het klinische na-onderzoek beschreven. Dit bestaat uit:
- een anamnestische evaluatie
- een orthopaedisch onderzoek van status locales en regionales, zowel van het arthrodesegebied als van de donorplaats. Hierbij wordt het begrip polsscore – een waardering van de stand in het geankyloseerde polsgewricht – geïntroduceerd, gefundeerd op gegevens uit de J.A.M.A. invaliditeitsgids (1958).
- een röntgenologische evaluatie, waardoor kon worden vastgesteld, of er sprake is van een onderbreking in de ossale continuïteit, het anatomisch niveau waarop dit zich bevindt, de uitgebreidheid van de arthrodese en de stand in de arthrodese van metacarpus t.o.v. distale radius.
- een ergonomische evaluatie, waaraan alleen de eenzijdig aangedane patiënten (61) zijn onderworpen. Hierbij wordt een evaluatiemethode beschreven, onderverdeeld in 4 blokken waarin de volgende functies kunnen worden onderzocht:
- blok 1: hand- en vingerfunctie
- blok 2: verschillende grepen, strek- en knijpkracht
- blok 3: testprogramma voor de functie van de bovenste extremiteit
- blok 4: tweehandige specifieke functies.

De per blok behaalde resultaten, de zogenoemde *blokscores* werden vervolgens gepresenteerd en geanalyseerd.
Hierbij is ook het dominantieverschuivingspatroon anamnestisch vastgesteld. Vervolgens is door de ergotherapeute beoordeeld in hoeverre de betrokken extremiteit functioneel goed bruikbaar en ingepast in het lichaamsschema is. Tenslotte is bij alle patiënten het stereognostisch vermogen gecontroleerd.

In hoofdstuk VI wordt ingegaan op de aspecten t.a.v. arbeids(on)geschiktheid en beroep. Hierbij worden pré- en postoperatieve beroepen vergeleken en het huidige werk van de patiënten geanalyseerd, waarbij ook begrippen als zwaarte van polsbelasting en mate van polsbeweging worden beschreven en gehanteerd. Hierbij is gebruik gemaakt van gegevens verstrekt door arbeidsdeskundigen van G.A.K. en G.M.D.

Hoofdstuk VII bevat de bespreking der resultaten. In de inleiding wordt een gedetailleerde literatuuroverzichtstabel gepresenteerd waarin auteur (met jaartal), patiëntenaantal, indicatie, operatietechniek en resultaat (d.w.z. beoordeling, beoordelingscriteria, complicaties en opmerkingen) zijn vermeld. Hieruit blijkt dat slechts 6 van de 51 auteurs duidelijk omschreven criteria ter beoordeling van het uiteindelijke resultaat hanteerden.

Hierna wordt het subjectieve resultaat-oordeel van de patiënt vermeld: 80.3% vindt zich verbeterd, 9.1% gelijk en 10.6% verslechterd, waarbij de patiënten als parameters: pijn, instabiliteit, greepvastheid en kracht gebruikten. 35 patiënten hadden nog restklachten. Bij 34 (van de 36) patiënten was het dominantieverschuivingspatroon verbeterd.

Bij de objectieve evaluatie wordt eerst het operatieresultaat geanalyseerd: van de 66 polsen bleken er 58 ankylotisch te zijn : 48 benig doorbouwd = geconsolideerd), 10 fibreus ankylotisch en in 8 gevallen was er een pseudoarthrose, d.w.z. beweeglijkheid in het arthrodesetraject. Deze getallen zijn vergeleken met de bevindingen bij het einde van de immobilisatieperiode.

Het blijkt dat 88% van de ankylotische polsgewrichten een stand heeft vallend binnen de criteria in de literatuur aan de 'functionele stand' gesteld.

Bij klinisch onderzoek blijken 41 patiënten pijnvrij te zijn; 30 patiënten hadden een normale (knijp)kracht.

Röntgenologisch blijkt het merendeel van de ossale defecten in het pseudoarthrosegebied zich op het carpometacarpale niveau te bevinden (12 van de 15).

Corticospongieuse (crista)spanen blijken tot een snellere, meer uitgebreide en homogenere botfusie te leiden dan corticale (tibia)spanen. Deze laatsten tonen echter minder standsverlies, hetwelk in palmaire en ulnaire richting blijkt op te treden.

Uit de vergelijking der operatietechnieken blijkt dat er géén onderscheid valt te maken tussen arthrosen die m.b.v. tibia- of iliumspanen tot stand zijn gebracht. D.w.z. bij beide technieken was er geen verschil in het aantal consolidaties, fibreuse ankylosen en pseudoarthrosen. Het aantal breuken in het donorbeen is hoog: bijna 20% (6 van de 31).

Hierna volgt een discussie over de uitgestrektheid van het arthrodesetraject, waarbij gebaseerd op de literatuur geconcludeerd kan worden dat een radiometacarpale arthrodese, waarbij alleen C.M.C. II en III worden meeverstijfd, de voorkeur verdient. Overigens kon dit in ons materiaal niet worden aangetoond i.v.m. de niet vergelijkbare getallen.

Bij het bespreken van de evaluatie van het functionele resultaat, blijkt duidelijk dat de oordeelsvorming over het al dan niet geslaagd zijn van de arthrodese niet alleen orthopaedisch technische elementen dient te omvatten, maar ook door ergonomische criteria wordt bepaald. Uit de ergonomi-

sche evaluatie blijkt n.l. dat onafhankelijk van de stand van de hand t.o.v. de onderarm in het polsgewricht de extremiteit nog redelijk tot zeer goed kan functioneren, waarbij het geen rol lijkt te spelen, of de arthrodese geconsolideerd (= benig doorbouwd), fibreus ankylotisch of zelfs in het geheel niet tot stand gekomen is.
Naar indicatiegroep verdeeld blijken patiënten uit de groep I en II ergonomisch duidelijk beter te scoren en de groep IV patiënten het slechtst.
De waarde van deze ergonomische evaluatiemethode, toegepast zowel preoperatief als postoperatief, wordt benadrukt.

Ten aanzien van arbeid en beroep blijkt de polsarthrodese een gunstig effect te hebben: het aantal 100% arbeidsongeschikten nam af van 40 tot 19 en het aantal 100% arbeidsgeschikten steeg van 1 tot 21. Dit effect speelde zich hoofdzakelijk in de indicatiegroepen II, III en IV af.
Ondanks de operatieve behandeling moesten 18 patiënten t.g.v. hun aandoening lichter werk gaan verrichten en 18 zelfs verdere arbeid opgeven.
Hierna zijn de totaalresultaten volgens eigen maatstaven beoordeeld, te weten:
- een ossale doorbouw van het arthrodesetraject
- subjectieve verbetering van pijn, kracht, greepvastheid en instabiliteit
- geen toename van functieverlies in naburige gewrichten van hand en onderarm
- een goede tot zéér goede ergonomiescore.

Slechts 28 (42.2%) van de 66 patiënten blijken hieraan te voldoen.
Beoordeeld naar de minder strenge en beperkte criteria gegeven door Merle d'Aubigné (1956), Dupont (1968), Linclau (1975) en Rayan (1982) blijken de resultaten in onze patiëntenserie duidelijk slechter.
De meeste overeenkomst wordt aangetroffen tussen de eigen serie en die van Merle d'Aubigné (1956), zowel qua samenstelling naar indicaties als naar aantal en in mindere mate met de patiëntengroep van Linclau (1975). Vergelijking met de groepen van Dupont (1968) – allen rheumapatiënten – en Rayan (1982) – slechts 14 gevallen – is nog minder goed mogelijk.

Tenslotte worden de conclusies en aanbevelingen gepresenteerd:

1. Gezien het subjectieve resultaat (t.a.v. pijn, kracht, greepvastheid en instabiliteit in 80,3% verbetering, in 9,1% gelijk gebleven en in 10,6% verslechtering) blijkt de indicatie tot verstijving van het polsgewricht juist te zijn geweest.

2. De technieken volgens Brittain-Ely en Butler leiden tot hetzelfde klinische en ergonomische resultaat.

3. Bij de Brittain-Ely techniek mag het risico van tibiaschachtfracturen van het donorbeen niet worden veronachtzaamd.

4. Crista-iliacaspanen geven een snellere en meer homogene botingroei dan tibiaspanen.

5. Tibiaspanen geven meer weerstand tegen de krachten die tot standsverlies aanleiding geven.

6. Patiënten met een t.p.v. het carpometacarpale niveau fibreus ankylotisch polsgewricht kunnen hetzelfde functionele resultaat scoren als degenen met een geconsolideerd polsgewricht. Bij een fibreus ankylotisch polsgewricht kunnen wel restklachten optreden. Een ankylotisch polsgewricht is geen garantie voor goede functie, ook met een pseudoarthrose kan een goede ergonomische functiescore bereikt worden.

7. Uit het feit dat patienten met verschillende stand van de hand t.o.v. de onderarm tot een gelijke functionele score kwamen, kan gesteld worden, dat een *algemeen geldende* "optimum position of function" niet is vast te stellen. Deze dient voor elk individu afzonderlijk ergonomisch te worden bepaald.

8. Het verdient aanbeveling een patient bij wie een arthrodese van het polsgewricht zal worden uitgevoerd, pre- en postoperatief ergonomisch te inventariseren en ergotherapeutisch na te behandelen.
   Hierbij kan de in deze studie ontwikkelde ergonomische evalutiemethode worden toegepast.
   In de pre-operatieve analyse dienen naast de A.D.L. ook de activiteiten t.a.v. beroep en arbeid te worden betrokken. Dit is mede bepalend voor de indicatie.

9. Gezien de literatuur lijkt een radiometacarpale arthrodese te prefereren boven een radiocarpale; hierbij dienen echter C.M.C. IV en V buiten de arthrodese te worden gelaten, gezien hun functionele betekenis voor de greepvorming.

APPENDIX I

From J.A.M.A.: a guide to the evaluation of permanent impairment of the extremities and back. Febr. 15, 1958.

	wrist function	*% loss of function of arm*	*% loss of function of wrist*
dorsiflexion max. 60°	max =	0%	0 %
	limited to 50° =	2%	6.6%
	40° =	3%	10 %
	30° =	5%	16.6%
	20° =	6%	20 %
	10° =	8%	26.7%
	0° =	10%	33.3%
palmar flexion max. 70°	max =	0%	0 %
	limited to = 60° =	2%	6.6%
	50° =	3%	10 %
	40° =	4%	16.7%
	30° =	6%	20 %
	20° =	8%	26.7%
	10° =	10%	33 %
	0° =	11%	36.7%
radial abduction max. 20°	max. =	0%	0 %
	limited to = 10° =	2%	6.7%
	0° abolished =	4%	13.7%
ulnar abduction max. 30°	max. =	0%	0 %
	limited to 20° =	2%	6.7%
	10° =	4%	13.3%
	0° =	5%	16.7%

Maximal loss of wrist function: 100%, equals 30% loss of function of the arm as a whole.

APPENDIX II

block 1

	group I	*group II*	*group III*	*group IV*	*total*
very good	6	10	4	–	20
good	5	8	5	3	21
fair	1	–	2	5	8
bad	–	–	2	5	7
very bad	–	–	–	5	5
	12	18	13	18	61

block 2

very good	2	2	–	–	4
good	8	12	4	5	29
fair	2	4	9	6	21
bad	–	–	–	7	7
very bad	–	–	–	–	–
	12	18	13	18	61

block 3

very good	6	6	3	1	16
good	4	10	7	1	22
fair	2	2	2	4	10
bad	–	–	1	8	9
very bad	–	–	–	4	4
	12	18	13	18	61

block 4

very good	4	6	2	–	12
good	6	8	4	5	23
fair	1	4	6	2	13
bad	1	–	1	6	8
very bad	–	–	–	5	5
	12	18	13	18	61

APPENDIX IIA

Survey block scores

Roman = clinically immobile (ankylotic)
Italic = clinically mobile (pseudarthrosis)

Block 1

	groupI		*group II*		*group III*		*group IV*		*total*	
very good	5	*1*	9	*1*	4	–	–	–	18	*2*
good	3	*2*	8	–	5	–	2	*1*	18	*3*
fair	–	*1*	–	–	2	–	5	–	7	*1*
bad	–	–	–	–	2	–	5	–	7	–
very bad	–	–	–	–	–	–	4	*1*	3	*1*
	8	*4*	17	*1*	13	*0*	16	*2*	53	*7*

Block 2

very good	2	–	2	–	–	–	–	–	4	–
good	6	*2*	11	*1*	4	–	4	*1*	25	*4*
fair	–	*2*	4	–	9	–	6	–	19	*2*
bad	–	–	–	–	–	–	5	–	5	–
very bad	–	–	–	–	–	–	1	–	1	*1*
	8	*4*	17	*1*	13	*0*	16	*1*	54	*7*

Block 3

very good	4	*2*	6	–	3	–	1	–	14	*2*
good	2	*2*	9	*1*	7	–	–	*1*	18	*4*
fair	2	–	2	–	2	–	4	–	10	–
bad	–	–	–	–	1	–	8	–	9	–
very bad	–	–	–	–	–	–	3	*1*	3	*1*
	8	*4*	17	*1*	13	*0*	16	*2*	54	*7*

Block 4

very good	3	*1*	6	–	2	–	–	–	11	*1*
good	3	*3*	8	–	4	–	4	*1*	19	*4*
fair	1	–	3	*1*	6	–	2	–	12	*1*
bad	1	–	–	–	1	–	6	–	8	–
very bad	–	–	–	–	–	–	4	*1*	4	*1*
	8	*4*	17	*1*	13	*0*	16	*2*	54	*7*

group I pat.nr.	**block score 1.**	**2.**	**3.**	**4.**	*wrist score*
13.°	2	2	1	2	3
18.°	1	1	1	1	3
53.°	1	1	1	1	3
67.°	1	2	2	3	4
11.*	2	2	3	4	3
20.*	1	2	2	2	3
25.*	2	2	3	2	2
29.*	1	2	1	1	3
16.**	2	2	1	1	2
40.**	1	3	1	2	5
49.**	2	2	2	2	2
62.**	3	3	2	2	2
Total 12					

group II pat.nr.	**block score 1.**	**2.**	**3.**	**4.**	*wrist score*
2.°	2	2	3	2	4
3.°	1	2	2	2	3
5.°	2	2	1	2	4
8.°	1	2	1	1	3
10.°	1	2	1	1	3
15.°	1	3	1	1	3
21.°	2	3	3	2	4
33.°	2	2	1	1	3
34.°	2	2	2	2	5
56.°	2	1	2	2	2
60.°	2	2	2	3	3
61.°	2	2	2	3	4
66.°	1	1	2	2	2
68.°	1	3	1	1	3
30.*	1	2	2	2	4
58.*	1	2	2	1	4
65.*	1	3	2	3	3
12**	1	2	2	3	2
Total 18					

° consolidated
* fibrous ankylosis
** pseudarthrosis

APPENDIX IIB (cont.)

group III **block score**	**1.**	**2.**	**3.**	**4.**	*wrist score*
pat.nr.					
1.°	3	3	2	3	3
4.°	1	3	1	2	3
7.°	1	2	2	2	3
19.°	4	3	3	3	3
26.°	2	3	2	2	5
43.°	4	3	4	4	3
52.°	1	2	1	1	3
54.°	2	3	2	3	4
55.°	2	3	2	3	3
57.°	2	2	2	3	4
63.°	3	3	2	2	3
32.*	2	3	3	3	3
59.*	1	2	1	1	4
Total 13					

group IV **block score**	**1.**	**2.**	**3.**	**4.**	*wrist score*
pat.nr.					
14.°	3	3	4	4	3
17.°	2	2	3	2	3
22.°	3	3	5	4	6
23.°	5	5	5	5	5
27.°	4	4	4	3	4
31.°	3	3	4	4	2
41.°	3	4	3	5	4
44.°	4	4	3	4	2
45.°	5	3	5	4	7
46.°	4	2	3	3	5
47.°	5	4	4	2	3
48.°	4	2	4	4	4
51.°	2	2	1	2	3
64.°	4	3	4	5	2
69.°	5	3	4	5	5
24.*	3	4	4	2	3
9.**	5	5	5	5	8
42.**	2	2	2	2	5
Total 18					

° consolidated
* fibrous ankylosis
** pseudarthrosis

For 5 wrists, of patients with bilateral lesions, no block scores could be determined: patients nrs. 6, 28, 35 (2x because operated on both wrists) and 50, all belonging to group III. This number includes 1 clinically mobile wrist.

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STELLINGEN

I

Onder ankylose dient die toestand te worden verstaan waarbij een aanvankelijke beweeglijkheid tussen twee botstukken is opgeheven. Deze klinische beoordeling kan door röntgenonderzoek onderscheiden worden in een ossale ankylose en een fibreuze ankylose.

II

Een analyse van de functie van de kruisbanden van het kniegewricht vraagt een gedetailleerde analyse van de interne structuur van deze ligamenten.

III

Nagegaan dient te worden of het relatief grote aanbod van patiënten met klachten van het bewegingsapparaat in verhouding staat tot de in het medisch curriculum aan het bewegingsapparaat besteedde onderwijstijd.

IV

Het physisch diagnostisch onderzoek van de lage rug is onvolledig zonder inwendig onderzoek.

V

Bij de interne fixatie van schachtfracturen van de onderste extremiteit verdient de "Verriegelungsnägel" methode van Grosse en Kempf de voorkeur boven de A.O. plaattechniek.

VI

Bij de conservatieve behandeling van de fractuur van het os scaphoideum kan worden volstaan met immobilisatie tot aan het elleboogsgewricht.

VII

Bij congenitale heupafwijkingen verdient real time high resolution sonografie als diagnostische techniek de voorkeur boven röntgenonderzoek.

VIII

De conventionele tomografie van de larynx en laryngopharynx moet worden beschouwd als een verouderd onderzoek. De laryngografie en de computertomografie verdienen de voorkeur.

IX

Bij de diagnostiek van de lumbale H.N.P. heeft C.T. onderzoek de voorkeur boven caudografie. Een eventuele caudografie dient pas na C.T. onderzoek plaats te vinden.

X

Bij de percutane botbiopsie moet de punctie bij voorkeur met een dunne naald geschieden.

XI

Bij de infectie preventie door middel van antibiotica bij een gewrichtsvervangende ingreep dient men zich niet alleen te richten op de per(i)-operatieve fase maar ook op de periode tot aan de wondgenezing.

XII

Bij het lopen óp schoenen met middelhoge en hoge hakken wordt de voorvoet sterk belast. Vooral de mediale voorvoet wordt overmatig en langdurig belast; zulks kan leiden tot beschadiging van het plantaire vetweefsel ter plaatse.

XIII

Een fusie van ziekenhuizen betekent meestal een fusie van problemen.